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More Simple Science

EARTH AND MAN

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HARPER & BROTHERS

Publishers

NEW YORK LONDON

MORE SIMPLE SCIENCE

Printed in the United States of America

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PREFACE

Simple Science, a previous volume by the same authors, dealt chiefly with the elements of mechanics, physics, chemistry and biology. It was felt, however, that some branches, such as geology and agricultural science, had been neglected, and that it would be useful to conclude with some brief account of the history and methods of science.

It is with these aims in view that the present volume has been prepared. We believe that the method of treatment adopted is new. Starting with some facts of physical geography, we proceed to discuss the earth's climatic belts and their effects on animal and plant life. Thence we pass to geology and so to evolution. After discussing the general question of the circulation of different chemical elements through life, we proceed to the particular application of this which is realized in agriculture. Here we begin with a chapter on soil which we believe to be the first popular presentation of modern views on Soil Science; and so pass to a discussion of the improvement of soils by fertilizers. Before considering the further aspect of agriculture which consists in the improvement of crops and live stock, we lay the foundations for such a discussion in a chapter on reproduction and development, bringing in elementary Mendelism later. In the final chapters we attempt to summarize the chief steps in the history of science and the principles and ideas underlying scientific discovery.

We hope that this will complete the task which we began in our previous volume *Simple Science*, and that the two books together will provide an adequate popular introduction to the concrete facts and achievements of science.

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ANDRADE AND HUXLEY

MORE SIMPLE SCIENCE

CHAPTER I

THE EARTH AND ITS CLIMATES

Classification and Adaptation—The Earth is Round—How the Earth Spins—Measuring Angles—Latitude and Longitude—Seasons and Climate—Why the Year has Different Seasons—The World's Air-Circulation—The World's Water-Circulation—The Earth's Belts of Climate—Life in the World's Cold Belts—The Temperate Lands and the Desert Belt—Life near the Equator

Classification and Adaptation

IN this Book we shall deal with some of the rules about living things in their relation to the planet Earth which serves as their home, ending up with some facts concerning man in his relation to the earth and to other living creatures.

First of all let us think of the variety of animals and plants. Most people do not realise how many different kinds there are. For instance, in England alone the number of different kinds of birds to be found is about 300, of butterflies and moths more than 2,000, and of beetles about 3,500. The number of different kinds of animals in the world is more than half a million, and every year scientists are discovering new ones, especially in the tropical regions. Of plants, too, there are several hundred thousand separate sorts.

We need to be able to bring some sort of order into this huge variety of living creatures. One way is to classify animals and plants according to the likenesses and differences in their plans of construction. On such a scheme a horse and a donkey would be very near together. Both they and dogs and cats would be put in a big

group which included all animals which possessed hair and fed their young on milk after birth (we call them all mammals). And all these would go in one still bigger group of animals with a backbone, which would also include birds; reptiles like snakes and lizards and tortoises; amphibians like frogs and newts; and fishes. This group is called the vertebrates. Most vertebrates have two pairs of limbs and a tail. Spiders, on the other hand, and insects and crabs could not be pigeon-holed in this group, as they have no backbone. However, they all resemble each other in possessing several pairs of many-jointed limbs, and in having their skeleton on the outside instead of the inside of their bodies. This group is called the group of arthropods, from the Greek words for jointed legs. Jelly-fish and sea-anemones would have to go in yet another big group, called the cœlenterates; and earthworms, leeches and lug-worms in another, called the annelids.

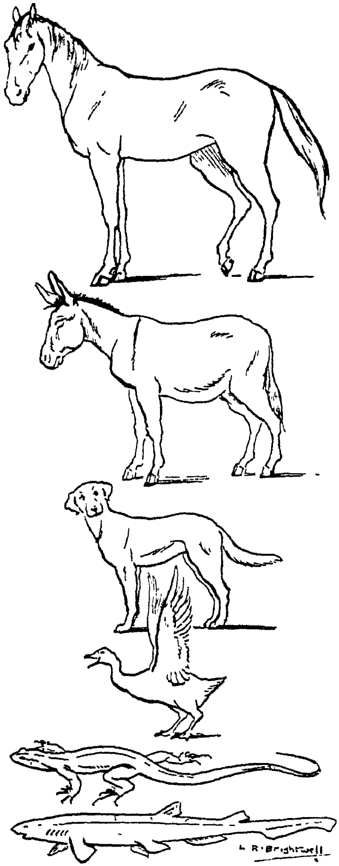


FIG. I.—*Classifying animals. Six kinds of vertebrates: horse, donkey, dog, duck, lizard, dog-fish.*

But there is another way in which we can bring some orderly arrangement into the enormous assemblage of animals and plants, and that is by thinking of them in relation to where and how they live. When we do this we see that they are always more or less suited to their surroundings. To take a very obvious example, an animal that is to be a success in the sea must be able to breathe in water and to swim, while one that is

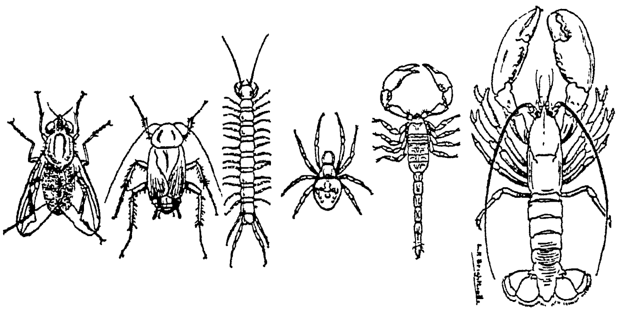


FIG. 2.—*Classifying animals. Six kinds of arthropods: fly, cockroach, centipede, spider, scorpion, lobster.*

to be a success out of water must be able to move easily on land and to breathe in air. A horse would be no more good in the sea than a herring on land. In the same way a water-lily could no more grow on a sand-dune than could a cactus in the middle of a pond.

This fitting of living things to their surroundings we call adaptation. But before we can go on to talk of this, we ought to know a little more of the various surroundings to which animals and plants have to be fitted. In other words, we shall have to learn a little geography. But to understand the facts of geography we shall have to talk about climate and the seasons, and to understand these

we shall have to look at the earth itself and see how it behaves and what is happening to it as it spins through space.

The Earth is Round

You all know that the earth is a huge round ball, which spins on itself like a top, and also circles round the sun. If anyone told you that the earth was flat and fixed, and that the sun went round it, you would think them very ignorant. But have you ever asked yourself what reasons you have for believing this about the earth? Probably the only reason you can find is that you have been told so

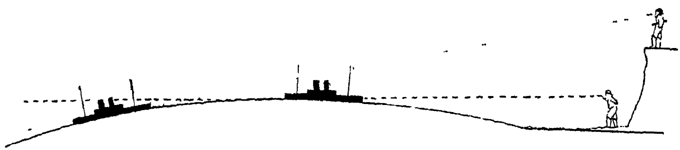


Fig. 3.—*How you can see that the earth is round. The man on the shore will only see the masts and funnels of the distant ship; but the man on the cliff will see all of her. (Of course the size of the ships and the men has been very much exaggerated in the picture, in proportion to the curve of the sea's surface.)*

when you were young or read it in a book. As a matter of fact, the real reasons are not at all easy to find, and men had lived on the earth for many thousands of years before they found out what shape it was and in what a surprising way it moved.

To look at, the earth seems quite flat. It has mountains and valleys in it, but the general level seems to be always the same. But really it is quite easy to see that the earth is not flat. If you are at the seaside on a clear day, and there is a steamer making out to sea, at first you will see the whole of the ship. But as it gets further away,

the lower part of it will begin to disappear, until after a time you can see only the upper decks and the funnels and the masts. She is what sailors call "hull down." Gradually, even if you have a telescope, the funnels will be lost to sight, and then the masts, until finally there is nothing to be seen but a trail of smoke.

The reason for this is that the earth is round, and so the surface of the sea is not flat, but gently curved. The ship sails on until the bulge of the curve hides her from your eyes, which can only see straight: the picture makes this plain. In the same way, if you are on a ship approaching a mountainous country, and the air is clear, the first thing you will see will be just the tops of the mountains, and gradually more and more of the lower slopes will come into view.

When the steamer is just hull down, as seen from the beach, you can get to see all of her again if you go up to the top of a cliff, because now you are high enough to see over the bulge between you and her. From the top of the cliff you will actually see more of the earth's surface.

The horizon is the name given to the edge of what you can see of the world's surface. The horizon has no fixed position. With the sea, for instance, the higher up you are, the further away the horizon will be. There is a simple rule which will tell you about this, only you must know the number of feet which you are above sea-level. Take the square root of this number. Then the distance of the horizon *in miles* will be about $1\frac{1}{4}$ times this. For instance, if you are at 25 feet, then the horizon will be nearly $1\frac{1}{4} \times \sqrt{25} = 6\frac{1}{4}$ miles away. But if you are 400 feet up, then the distance of the horizon will be about $1\frac{1}{4} \times \sqrt{400} = 25$ miles.

Then of course the best proof that the earth is a sphere

is that you can sail right round it and come back to where you started. The first man to do this was the explorer Magellan in 1520. But it was the firm belief that the earth was spherical and that men could sail round it which set Columbus off on his voyage. Europeans had discovered China and the Indies, with their silks and spice and all their other riches, but to get to them they had either to go thousands of miles overland by caravan, or else sail right round the southern end of Africa and then across by India and Malay. Columbus said to himself, "If the world is round, instead of going all this long and difficult way to the east to reach the Indies, I can get there by sailing straight across the ocean to the west. Once I have found a route this way, trade with those distant places will be much easier."

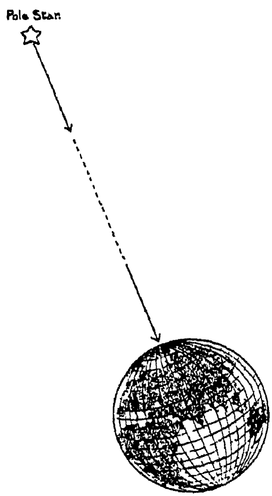


FIG. 4.—*The pole star will never appear directly overhead except from the North Pole. It cannot be seen at all from anywhere in the southern hemisphere.*

As a matter of fact, though his general idea was right, his calculations about the size of the earth were wrong. He never dreamt that to the west, between Europe and the East Indies, there was all of America and then another huge ocean. When he at last found land, he thought he had got to the Indies. It was not long before the mistake was discovered: but the islands he found are still called the West Indies, reminding us of Columbus' lucky mistake, without which he would never have discovered

the New World, as North and South America were christened.

Another way in which we can show that the earth is round is by looking at the stars. On p. 5 of "Simple Science" we spoke of the pole star, which appears fixed while the other stars circle round it. If you travel north or south, however, the pole star will seem to change its position in the sky. If you were at the North Pole you would have to look straight overhead to see the pole star. If you were in Africa, close to the equator, the pole star would be only just above the horizon, and if you went to Australia, you could not see the pole star at all. In England, the pole star appears rather more than halfway between the horizon and the zenith, which means the point of the sky which is right overhead. If you look at the picture, you will see that this is what you would expect if the earth were a ball; but it could not happen if the earth were flat.

How the Earth Spins

Then we have always been told that the earth is spinning round like a top, or rotating on its own axis, as it is called in science. But how is it possible for us to believe that the earth is rotating and the sun fixed when every day we can see the sun move with our own eyes? We see it rise in the east, get higher in the sky until midday, then get lower and finally set in the west.

As a matter of fact, this apparent motion of the sun, though it tells us that either the sun or the earth is moving, does not enable us to say which of them it is. When you are in a train at a station, and another train next to you, which you are watching, begins to pull out, you often think that your own train is moving in the opposite

direction. In this case you soon find out your mistake, partly because you get none of the joggling which trains make when they move, partly because when you look out of the other window you see that the platform and the people are still there, and not slipping away from you. But suppose that trains moved so smoothly that there was no joggling, and suppose that there was nothing to be seen through the windows but the other train. Then you would find it quite impossible to tell whether it was the other train which was moving, or your own. All you could say was that a movement was taking place. In scientific phrase, we would say that you and the other train were in relative motion. You could easily find out how fast this motion was by counting the carriages as they moved past, but you could not tell which train was fixed and which was moving unless you had something else besides your train and the other train to judge by.

It is the same with the earth and the sun. Clearly the sun and the earth must be moving relative to each other, or the sun would not appear first in the east, then high up in the sky, and then towards the west. But to decide which of the two is moving is not at all simple.

There is one thing, however, which would be very difficult to understand if the earth were fixed. If the earth were fixed, then not only the sun but the stars must be going round it once in every twenty-four hours. But we know that the stars are enormous, many of them much bigger than our sun, and that they are millions of millions of miles away. If the stars were going round the earth, they would have to be travelling at terrific speeds. It is much simpler to think of our globe spinning round its own axis than it is to imagine all these many thousands of huge stars circling round the one little body, the earth.

Besides this, there are complicated reasons discovered by astronomers which make us sure that it is the earth which is spinning, and not all the rest of the universe.

The reasons which make us believe that the earth is travelling round and round the sun as well as spinning round on itself are also not easy to understand. They have to do chiefly with the other planets. Astronomers have studied very carefully the way the planets move relative to the earth. If the earth and the other planets were not travelling round the sun, but instead the earth were the centre of all things, then the planets would have to be moving in an extremely complicated sort of way; while if the motions of all the planets, earth included, are governed by the sun, so that they all circle round it, their movements become simple and easy to describe.

The next thing is to describe the way in which the earth does actually move. When we understand this, we shall see what important consequences it has for the plants and animals and human beings that live on the earth's surface.

Let us first think only of the spinning of the earth. When a top is spun really well, so that we say it is "sleeping," there are two places on its surface—its point and the centre of the top of its handle—which are not moving at all. If you could draw a line right through the top between these two places, it would be motionless and all the rest of the top would be spinning round it. This line is called the axis of rotation of the top (rotation simply means spinning). The earth, too, must have its axis of rotation, and on the earth's surface at each end of the axis there must be a spot which is not spinning. These two places are what we call the poles of the earth—the North Pole and the South Pole. If you were to stand actually *on*

either of the poles for twenty-four hours, you would simply be turned through a full circle by the spin of the earth.

If you think of it, there must be a line right round the middle of the world on which a man would always be half-way between the two poles. This is called the equator, which means equalizer, because it divides the world into two equal halves.

Since the earth is round, at any moment half of it will be lit up by the sun's rays, while the other half will be in the dark. And since it is spinning round its own axis, places on its surface will be spun out of the light into the dark shadow and back, over and over again,—in other words day and night are the result of the earth's rotation round its own axis (Fig. 10).

The fact that our day is twenty-four hours long is just another way of saying that our earth takes twenty-four hours to turn once round on its axis. If it happened to take some other time to turn round, the day would be a different number of hours long.

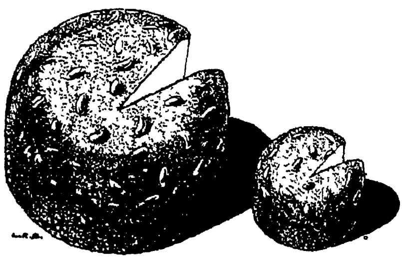


FIG. 5.—*Measuring angles. The slice cut out of the big cake has much more to eat in it than the slice cut out of the little cake. But the angle of both slices is the same.*

Measuring Angles

Before going any further, let us explain how we fix the position of any place on the earth's surface. In geometry, a circle is divided for convenience into 360 degrees. A degree measures a definite-sized angle at the

centre of the circle: the size of the angle represented by, say, 22½ degrees is always the same, whether the circle you are measuring is big or small. A slice of a round cake measuring 22½ degrees, as in the picture, will always be one-sixteenth of the cake. Whether there is a great deal to eat in it, or only a little, depends on how big the cake is. A right angle is always a quarter of a circle, in other words, 90 degrees. *Degrees* is generally written as a little circle after the number—for instance, the number of degrees in a right angle is written 90°.

To understand about angles you can do various simple experiments. First of all draw a small circle and a very big circle, and in each of them mark out an angle measuring the same number of degrees. An angle of 45° is easy to do, because it is one-eighth of the whole circle. Then measure the radius of the circles (that is to say, the distance from the centre to the circumference) and also the *arc* (that is to say, the piece of the circumference) which is inside the angle you have drawn. In the picture, AB, AC, and PQ, PR are each a radius, while the arcs to be measured are BC and QR. You can measure the arc with a piece of string which you then lay on a ruler. You will find that in both circles the proportion between the arc and the radius is the same; it will always be the same whatever the size of your circle, provided that you always take the same-sized angle. Two angles are the same size if you can place the lines which enclose the one exactly on the lines

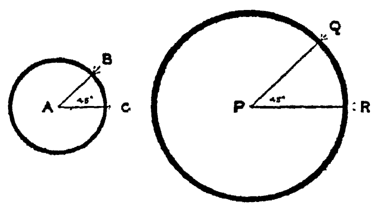


FIG. 6.—*Measuring angles. An angle of 45° in a small circle and in a large circle.*

which enclose the other, or, as the geometers say, if you can superpose them.

If you imagine lines drawn to your eye from two extreme points of a body at which you are looking, then the angle between these lines is spoken of as the angle subtended at your eye by the body. The angle which a thing subtends will change with the distance which it is from your eye; the further it is away the smaller will be the angle which it subtends. If you put up a series of sticks all of the same height across a field or open space, the angle which each subtends gets bigger the nearer the

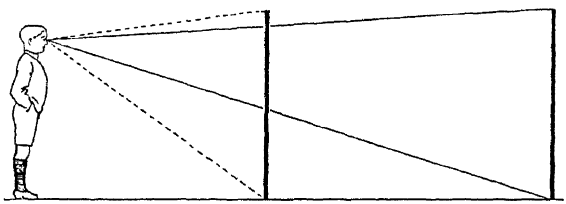


Fig. 7.—*A stick close to you subtends a bigger angle to your eye than a stick of the same size further away.*

stick is to you. You can easily see this by measuring the distance of each stick, drawing small-scale plans of the sticks and the distances, and then measuring the angles with a protractor.

On a clear night with a full moon, if you fix a halfpenny in a clamp, you can find what distance you must be from the halfpenny for it just to cover the moon. You will find that it is about 9 feet, while a halfpenny is just 1 inch across, and we know that the moon's distance from the earth is 240,000 miles. As a matter of fact the moon is not always the same distance away from the earth, but its average distance is nearly 240,000 miles, so we will take

that. From these facts we can calculate the moon's diameter (which means the distance from one side of it to the other, passing through the centre); for the proportion between the moon's distance and its diameter will be the same as the proportion between 9 feet and 1 inch; 9 feet is 108 inches, so the diameter of the moon 240,000 ÷ 108 = 2,222 miles. As a matter of fact, the halfpenny would exactly cover the moon at about 9 feet 3 inches from your eye, and the moon's diameter is actually 2,160 miles. The fact that smaller things that are nearer subtend the same angle as bigger things that are farther away is

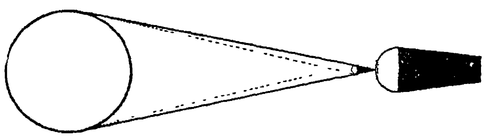


FIG. 8.—*How an eclipse of the sun occurs. The moon is much smaller than the sun, but is much nearer to the earth, and subtends almost the same angle as the sun, and so when it happens to come exactly between the earth and the sun, the sun is eclipsed behind it.*

important in considering eclipses of the sun (Fig. 8); and see "Simple Science," p. 540.

It is very important to be able to say just how far up in the sky, between the horizon and the overhead point (or zenith), a star or the sun happens to be. This is done by measuring the angle between the star and the horizon. With the sun, you can measure this for yourselves. You must take a straight stick or pole whose height you know, set it on a level piece of vertically upright ground, and then mark the position of the end of its shadow. If you do this at intervals throughout the day, you will find two things. First, the direction of the shadow changes. In the

morning it will point to the west, in the middle of the day to the north, in the evening to the east. This is, of course, because the position in which the sun appears in the sky changes as the earth spins round. Secondly, the length of the shadow changes. It is long in the morning, short in the middle of the day, and long again in the evening. If you mark the position of the end carefully every few minutes from half-past eleven to half-past twelve, you will find it is shortest at precisely twelve o'clock. Do not forget that in summer you will be having "summer time," which means that the real twelve o'clock midday will be when your clocks are marking one o'clock.

This is rather a rough method. To measure the sun's angle above the horizon accurately, people now use an instrument called a sextant. If you ever travel across the ocean, at noon on every day when the sun is out you will see the captain taking the height of the sun with his sextant. This is what sailors call "shooting the sun."

The captain does this in order to find out something about the position of his ship on the surface of the earth. Let us suppose it is the 21st of March (the reason for choosing this date we shall find out later). Then if his ship were sailing across the equator, the sun would be exactly overhead at midday: its angle above the horizon would be 90°. If he were a polar explorer and was at the North Pole, the top of the sun would just peep over the horizon at noon and soon would sink out of sight again: its angle above the horizon would be 0°. If the ship were leaving the mouth of the Thames, the sun's height at midday would be about 38½° above the horizon. Knowing the sun's height at noon above the horizon tells him what his position is between the equator and the pole.

LATITUDE AND LONGITUDE

To describe accurately the position of a place between the equator and the pole, we use the equator as a fixed point, and call it nought degrees—0°. From the equator to either one of the poles is a quarter of a circle or 90°. Accordingly we can describe the position of a place by saying it is so many degrees north or south of the equator. All points on a circle parallel to the equator are the same number of degrees north (or south) of the equator.

These degrees, which tell us how far a point is north or south of the equator, are called degrees of latitude, which means breadth: this is because the circles corresponding to a given degree run broadwise round the earth. Since giving the degree of latitude only tells us that the place is somewhere on a certain circle parallel to the equator, in order to fix the position of a place exactly, we also want to know where it is to the east or the west on its particular circle of latitude.

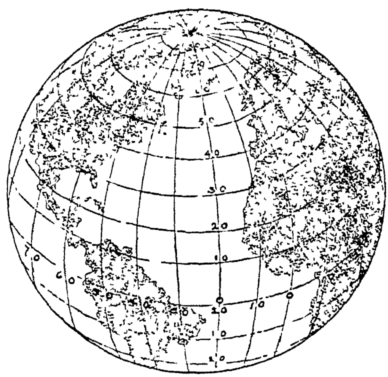


FIG. 9.—*Longitude and latitude. A globe with every tenth meridian of longitude and every tenth circle of latitude marked on it.*

To understand about this, we must think a little about the time of day in different parts of the world.

When the sun is at its highest in the sky, we call it midday. If you think of the earth turning round on its axis, you will see that midday will come to a great many places at the

same moment. When it is midday in London, for instance, it must also be midday for all the places directly north of it and all the places directly south of it. If you were to draw a line due north and south through London and continue it until it reached the two poles, all the places on that line would have midday at the same instant. Such a line is called a meridian, which means a midday line. Six hours later, it will be midday for another set of places on another meridian. But six hours is a quarter of twenty-four, so this other meridian must be a quarter of the way round the earth. Since there are 360° in a complete circle, the two particular meridians we have taken as our example are a quarter of 360°, that is to say, 90°, apart.

If we fix some particular meridian as our starting-point, we can measure all the other meridians as so many degrees distant from this starting-point. As a matter of fact, the meridian used as a starting-point is that which passes through London, or, to be precise, through the Royal Observatory at Greenwich. This is marked on maps as 0°, and other meridians are spoken of as so many degrees east or west of it. For instance, New York is on a meridian almost 74° W. of Greenwich.

These degrees east and west of the meridian of Greenwich are called degrees of longitude. The meridians of longitude cross the circles of latitude at right angles. All the meridians meet at the poles, so that the distance between one degree of longitude and the next is biggest at the equator, and gets narrower as you go north or south. But the circles of latitude run parallel with the equator and with each other, so that the distance between one degree of latitude and the next is the same all the way round the earth.

We can now see how it is that the captain of a ship can

tell what latitude he is in by finding out how high the sun gets above the horizon at midday. But how is he to know his longitude? This was for centuries a problem that could not be solved. The only practical way is to have a very accurate watch, called a chronometer, and set it to Greenwich time before starting. When the captain is "shooting the sun" with his sextant, he can tell exactly when midday is, by finding out when the sun is highest above the horizon. Then he looks at his clock, and from the difference between the time it tells, which is the right time for Greenwich, and the time where he is, which is midday, he knows what longitude he is in.

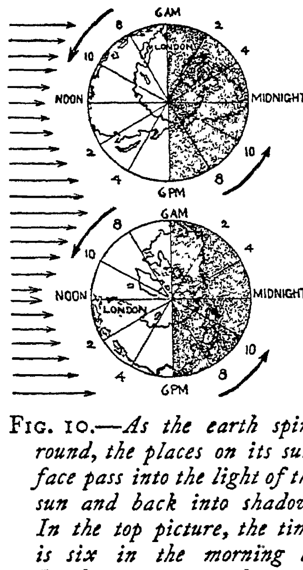


FIG. 10.—*As the earth spins round, the places on its surface pass into the light of the sun and back into shadow. In the top picture, the time is six in the morning at London on one of the equinoxes. In the lower picture, it is noon at London.*

For instance, suppose that when it is midday with him, Greenwich time, as given by his chronometer, is 6 o'clock in the evening. That is 6 hours' difference, which means that he must be a quarter of the way round the world (that is 90° of longitude) from Greenwich. But is he a quarter of the way round to the east or to the west? That, too, is easy to think out. The sun seems to rise in the east and move across to the west: this means that the earth is spinning in the opposite direction, from west to east. So as the time is earlier where he is than at Greenwich, he must be to the *west* of Greenwich, and

it will take him six hours to spin round to the position in which Greenwich was when he took his observation. His longitude is 90° W. If he had found that Greenwich time was 10 o'clock in the morning when it was midday with him, then he must be one-twelfth of the way round the world, and must be *east* of Greenwich: his longitude is 30° E.

It is easy to understand how to do this if you have an accurate clock; but it is exceedingly hard to make a clock which is accurate enough. Even if your clock only gained or lost 10 seconds a day, that would mean 5 minutes in a month; a mistake of 5 minutes in the time would mean a mistake of over a degree of longitude, and this might have very serious results.

It is so important for sailors to have accurate chronometers that in 1713 the British Government offered a prize of £20,000 to anyone who would make a chronometer which would not gain or lose more than three seconds in a day; this would enable a ship to determine its longitude to within 30 nautical miles at the end of a six weeks' voyage. In 1762 a famous clock-maker called Harrison produced a chronometer which was even better than this (the original instrument can still be seen in the Royal Observatory at Greenwich), and he was paid the reward in full, though not until eleven years had elapsed. The best modern chronometers are even more accurate. They do not gain or lose more than a second a day, or, as is usually said in science, they have an error of less than a second a day.

Since the invention of wireless, chronometers have become less important, for any ship with wireless can pick up the time-signal which is sent out from Greenwich every day precisely at noon.

Now we have described how people find the latitude

and the longitude of wherever they may be. By giving both the latitude and the longitude of a place, you describe its position completely. For purposes of exact description, each degree is divided into 60 minutes, and each minute into 60 seconds. A minute of latitude is one sea-mile, which is nearly $1\frac{1}{6}$ ordinary miles. The sign for minutes is written ′, that for seconds is written ″. The position of Greenwich is lat. 51°29′ N., long. 0°0′0″; New York is in lat. 40°43′ N., long. 74°1′ W.; Cape Town is in lat. 33°56′ S., long. 18°25′ E.

Of course there are no actual lines on the earth to mark the equator or the degrees of latitude and longitude, any more than there is a flagstaff to mark the North Pole. The lines on the earth are imaginary ones; it is only on maps or globes that real lines are marked.

You must also remember that the north is not really "up" and the south "down." It is convenient always to have all our maps the same way up, and people have chosen to put north at the top. But they might just as well have put south at the top, or east-north-east. The best way to study a map is to put it flat on a table or the floor and then turn it round until north on the map points in the real north direction.

Seasons and Climate

Besides spinning on its own axis, or rotating, the earth travels round the sun. The path in which the earth moves round the sun is called its orbit. The earth's orbit lies all in one plane, that is, it is as if drawn on a gigantic flat sheet, and is not like a switchback, which goes up and down as well as round and round.

It just happens that the earth's day is 24 hours long, and the earth's year 365 days and a little over. As we saw

in the first chapter of Book I, there are other bodies besides the earth which go round the sun: these are the various planets. Mercury and Venus are closer to the sun than the earth is, and Mars, Jupiter, Saturn, Uranus, Neptune and Pluto are further away. There is a picture showing the sizes of the different planets in "Simple Science," p. 302 (Fig. 70).

Mercury has a year which lasts less than 88 of our days, but its day is much longer than ours. Saturn, on the other hand, has its year nearly thirty times as long as ours, but its day is only just over 10 hours. We do not know how long Neptune's day is, because with our telescopes we cannot see anything on its surface and so cannot tell how fast this planet spins on its axis, but its year—the time it takes to go once round the sun—is 165 of our earth years.

Why the Year has Different Seasons

There remains one further fact about the earth's movements. Its axis does not stand at right angles to the plane of its orbit, but is tilted. When a top is not spinning quite straight up, its axis tilts first in one way then in another. The earth, however, does not behave in this way. Its axis is always tilted in the same general direction, and so is always parallel to a certain fixed straight line, which stands obliquely to the plane of the earth's orbit (Fig. 11).

The consequence is that when the earth is at one point of its orbit, the north end of its axis is tilted towards the sun, while at the opposite side of the orbit it is tilted away from the sun. The amount the earth's axis is tilted is almost exactly 23½ degrees—a little over a quarter of a right angle.

This fact of the earth spinning in a tilted position is extremely important for us human beings. If the earth

were spinning straight up, then day and night would always be the same length, and there would be no difference between summer and winter, no seasons in the year. Life is much more interesting because of this fact of the earth being tilted.

Let us see how it is that the tilting of the earth produces the seasons. In the earth's journey round the sun each year there comes a time when the tilt of its axis brings the surface of the earth at the North Pole as nearly facing the sun as it ever is. The South Pole, of course, will meanwhile be facing away from the sun as much as it ever can be. If you have a globe available at home, you can use it to understand just how this will happen, taking an electric light or a candle to represent the sun. If you have no proper globe you can take a football or a ball of clay or plasticine instead, marking on it the poles and the equator and the positions of some of the countries: you must, of course, be careful to keep it tilted through a quarter of a right angle. A globe is generally made with its axis tilted relative to the table on which it stands, by an amount which is just right if the earth's motion in its orbit is imitated by pushing the globe round on the table.

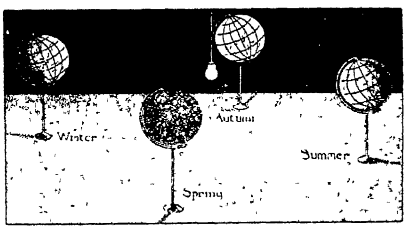


FIG. 11. — *To show how the tilting of the earth's axis causes the seasons. The globe is shown in four positions corresponding to midsummer, autumn equinox, midwinter, and spring equinox in the northern hemisphere. The seasons in the southern hemisphere will be the opposite of those in the northern.*

When the North Pole is tilted towards the sun, the daily spinning of the globe will not take the

pole out of the light into darkness: there will be no night during the twenty-four hours. The South Pole, on the other hand, will at this time have nothing but darkness. Places north of the Equator will get light for more than half of the twenty-four hours, which means a long day and a short night; while those south of the equator will have a short day and a long night.

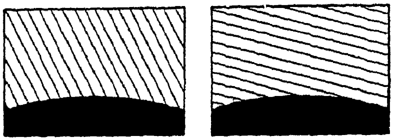


FIG. 12.—*In England, during the summer (left) the sun's rays strike the earth's surface more nearly straight. During the winter (right) they strike it more slantingly.*

In addition, the sun's rays will strike the northern places more nearly at right angles, and the sun will be more nearly overhead in the sky there; while at places in the same latitude south of the equator the sun will be much lower in the sky, and therefore its light will be much more slanting when it reaches the earth's surface.

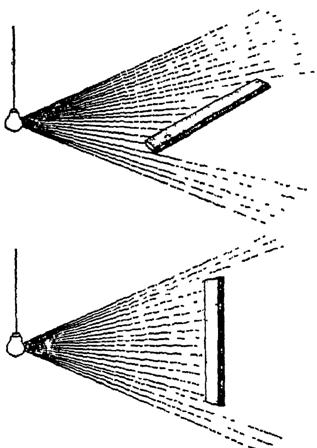


FIG. 13.—*A board set slantwise to the direction of light receives much less light than if it is set at right-angles to it.*

This will mean, of course, that the northern places will receive much more light and heat in the twenty-four hours

than corresponding places south of the equator. In fact the northern hemisphere will be having its summer, while the southern hemisphere will be having its winter.

You can see what a difference will be made by light striking the earth's surface slantwise by taking a flat board or piece of cardboard, as in the picture, and holding it first at right angles to the rays of light from a lamp, and then at the same distance from the light, but slantingly. When it is held slantingly, the same amount of surface is being hit by much less light. If you use a narrow beam of light, for instance from an electric torch, you will see that the light in the beam is spread over a much greater amount of the board's surface when the board is slanted.

Six months later, the earth will be at the other side of its path round the sun, so that its South Pole is tilted towards the sun and its North Pole away from the sun. Now it will be summer in the southern hemisphere, and winter in the northern.

In between the times of summer and winter the earth will pass through two positions when the tilt of the poles is neither towards nor away from the sun, but sideways. When this is so day and night will be exactly equal over the whole earth, twelve hours each at both poles as well as at the equator. These two times are called the equinoxes, from Latin words which mean equal night. The spring equinox comes between winter and summer, the autumn equinox between summer and winter. Of course when it is the spring equinox in the northern hemisphere, it will be the autumn equinox in the southern.

At the equinoxes, the sun at midday will be directly overhead on the equator (that is why we chose March 21, which is the date of the northern spring equinox, as

the day which we supposed earlier in the chapter that the captain was measuring the height of the sun at midday). But on Midsummer Day in the northern summer, it will be overhead at midday at places a certain distance north of the equator. These places will of course all lie on one circle of latitude, and midday will come to them one after another during the twenty-four hours. The number of degrees of latitude between the equator and this circle of places will be the same as the number of degrees through which the earth's axis is tilted, as you can see from the pictures (Figs. 11, 14).

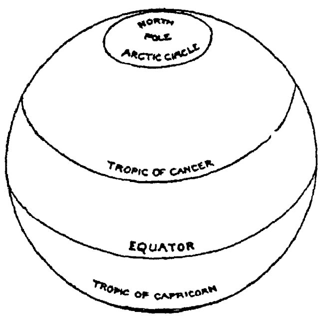


FIG. 14.—*A globe, seen from the same angle as the globe in Fig. 9, with the arctic circle, the two tropics and the equator marked on it.*

Of course there will be a corresponding circle of places south of the equator where the sun will be directly overhead at the southern midsummer, and this will be the same distance south of the equator. These two lines are called the tropics. It is only between the two tropics that the sun will ever be directly overhead.

Again, at the northern midsummer, not only will the North Pole itself receive the sun's rays all the time, but the sun will be above the horizon throughout the twenty-four hours over quite a big area of the earth's surface. At places which are the same distance from the pole as the tropics are from the equator, the sun at midnight will dip so as just to touch the horizon and then begin to mount again without ever setting. A line round the North Pole through this circle of places is

called the arctic circle, and the corresponding line round the South Pole is called the antarctic circle.

Though the parts of the earth within the arctic or antarctic circles have sunshine almost all the time during their summer, yet the sun is never very high in the sky there, even at midday, and the sun's rays strike the earth's surface very slantingly, which means that they have little heating power. Besides, there is all the winter when the sun does not rise at all for weeks or months, and the earth's surface can go on losing heat by radiating it away into space, so that even when the summer does come, there is a great accumulation of ice and snow to melt.

In the tropics, on the other hand, the sun can warm the earth much more because it strikes so nearly at right angles, and there are never any long nights during which a great deal of heat can leak away. Besides this, there is another reason for the tropics being warmer. Hot air can hold much more water vapour than cold air; and this extra moisture in the hot air of the tropics acts rather like a blanket, hindering the escape of heat during the nights, while in desert regions, however hot by day, the heat can escape much more easily at night through the dry air, and the nights are often quite cold. It is for these reasons that the polar regions, inside the arctic and antarctic circles, are cold, and the tropical zone (zone is the Greek word for belt), between the two tropics, is hot, while the belts between, which are called the temperate zones, have a moderately warm climate.

There would be differences in climate between different regions of the earth even if the earth's axis was not tilted. But the tilting makes the differences much bigger than they otherwise would be. For instance, there is hardly any difference between summer and winter in the tropics, but

the farther north or south you go, the more different the seasons get, until at the poles the difference is as complete as it could be, the day lasting for all the six months of summer, and the night for all the six months of winter. If the earth were not tilted, this would not be the case; day and night would be equal all over the earth's surface, and the differences in climate between the poles and the equator would depend only on the fact that the sun's rays struck the poles more slantingly; and there would be no seasons at all anywhere on the earth.

The World's Air Circulation

If the surface of the earth were all covered by sea, the climate would change steadily, in a regular way, as you went from the equator towards the poles. All the places on one circle of latitude would have the same climate, and, if you knew how warm one place was and how much rain it got, you could be sure that all the other places on the same latitude would have the same temperature and the same rainfall.

But in reality, things are not so simple as that. For instance, if you look at the map, you will see that London is in the same latitude as Southern Labrador; yet London has a mild temperate climate, while the climate of Labrador is very severe, almost arctic. The chief reason why climate does not change regularly with latitude is because there is land as well as water, and because the land is not arranged regularly on the surface of the globe.

Climates on land are more severe. The land warms up more quickly than the sea under the sun's rays, but also cools off more quickly when it is dark. So the difference between day and night, and also the difference between winter and summer, will be greater over a mass of land

than over the ocean in the same latitude. Also, as we shall describe more in detail in the next section, ocean currents are transporting heat by convection ("Simple Science," p. 299) from one part of the sea to another, so that near the equator the sea will be cooler than it would be if there were no currents, and near the poles it will be warmer. For this and other reasons, near the equator the continents will be hotter than the oceans, while near the poles they will be colder.

Besides this, there will be a difference in moisture. Most of the rain that falls on land has come from the sea. Winds from the ocean consist of air which has been able to take up plenty of water-vapour from the surface of the sea; if this air is cooled in any way, as, for instance, by rising when it has to cross a mountain range, it can no longer hold so much water-vapour, and the water-vapour condenses into drops which fall down as rain. The further the winds have blown inland, the more water-vapour they will have lost, and the less there will be to fall as rain. This will be especially marked if the prevailing wind crosses a high range of mountains on its way from the sea; then there will be very little water-vapour left in it to bring rain to the countries on the lee side of the mountains. We have already seen that water-vapour acts as a blanket for heat, so not only will the middle of a continent tend to have less rain than the edges, but it will also have a more extreme climate, with greater heat in summer and greater cold in winter.

You all know that it is colder, on the average, on top of a high mountain than on a low-lying plain; and it is in general true that on land that is high up the average temperature is lower than on the sea or on land near sea-level. As a result, wherever there are high lands near the poles, snow will accumulate faster than it can melt and

great snow-fields are formed. The weight of the top layers of snow presses on the layers below and squeezes them into solid ice, so that high land near the poles is covered by huge mantles of ice overlain by snow, which are generally called ice-caps. The ice-cap in the middle of Greenland is several thousand feet thick; in some places its thickness is probably about a mile and a half.

FIG. 15.—*An arctic scene. The Eskimo is waiting for a seal to come up to breathe at a hole in the sea-ice: he has already harpooned one seal. In the background, a glacier descends from the mountains into the sea: a few small icebergs have broken off from it.*

Once ice-caps are formed they have an effect on the climate. They make the climate colder in two ways. For one thing, they cool the air that passes over them, and for another they cool the sea round about. The way they cool the sea is by forcing ice into it. Although ice is a solid, yet under great pressure it will flow like a liquid, only very slowly. So, as the hundreds or thousands of feet of snow and ice pile up over high polar lands, their enormous

pressure squeezes the ice outwards round the edges of the ice-cap. If the ice-cap is broken by mountains, the ice flows out along the valleys. The rivers of ice in the valleys we call glaciers. In the polar regions the glaciers are generally pushed right down into the sea. But if the ice-cap is thick enough it will cover the whole coast, and spread out over the sea as a huge floating sheet of ice. In either case, big bits of ice break off into the sea from the edge of the ice, float away as icebergs, and gradually melt; and since, as we saw in "Simple Science," p. 312, it takes a great deal of heat to melt ice, this makes the sea in the neighbourhood much colder than it otherwise would be. There is a picture of an iceberg on p. 146 of "Simple Science."

This effect of high land near the poles in making the climate colder is very clearly shown when we compare the arctic with the antarctic. All round the North Pole is sea, covering about half the region inside the arctic circle. But the South Pole is more than ten thousand feet above sea-level, in the middle of a continent covering perhaps three-quarters of the region inside the antarctic circle, and with high plateaus and big mountain ranges in it. It is covered with an enormous ice-cap, which at one point sticks out into the sea and makes a high ice-cliff hundreds of miles long, which is called the Great Ice Barrier. Huge icebergs, sometimes many miles long, break off from this and float away. As a result, the climate all round the antarctic continent is very cold. If you compare the average temperature of the northern and southern hemispheres, as given in a good atlas, you will see that in the temperate zones places in the southern hemisphere are much colder than places on the same latitude north of the equator.

We must also say a word about the effects of winds. Hot air rises and cool air sinks. So there must be some

sort of a regular air-circulation over the surface of the globe. To take the place of the air that rises near the equator, more air will be sucked in from north and south, and so we shall get winds steadily blowing towards the equator from both sides.

At first sight we should expect these winds to blow due north and south. But this would be wrong, because we should be forgetting the fact of the earth's rotation, and this, strange as it may seem at first, has an influence on the direction of air or water which is flowing north or south over the earth's surface.

In a spinning top, everything except the axis is moving. But obviously some parts are moving faster than others, and the part which is moving the fastest is the part farthest from its axis. The same thing is true of the earth. A man near one of the poles travels round a very small circle in the twenty-four hours; the further he is from the pole, the bigger the distance he is carried round in the day and therefore the faster he is moving, until when he is on the equator, halfway between the poles, he will be moving farthest and fastest. As the earth is nearly 25,000 miles round, and as it goes round once in every twenty-four hours, a man standing on the equator is travelling round the earth's axis at rather over 1,000 miles an hour (over 17 miles a minute).

Now think of a current of air—a wind, that is—in the northern hemisphere blowing due south towards the equator. It is moving south over the earth's surface; but also, like the rest of the earth, it is spinning round from west to east. But the nearer it gets to the equator, the faster the earth below it is moving. So it gets, as it were, left behind by the earth. As the earth is spinning towards the east, this will mean that, to a man standing on the

earth, the wind will have a movement towards the west. But it also goes on with the movement with which it started towards the south.

When anything is trying to move in two directions like this, the direction in which it will actually move will be in between. If an aeroplane is flying due south by compass at the rate of 60 miles an hour, and there is an east wind blowing at 60 miles an hour, the aeroplane will actually travel south-west. Just the same will happen with our wind. The combination of its original movement to the south, with the movement towards the west which it has got because the earth is moving faster than it, will make it move south-west.

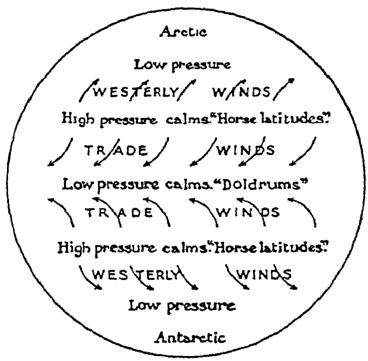


FIG. 16.—*A diagram to show the main arrangements of air-pressure and winds on the earth's surface. The arrangement is really more complicated: it would only be as simple as this if the earth were all covered with sea.*

We always speak of winds by the direction from which they come. So the rotation of the earth turns what ought to be a north wind into a north-east wind.

The same thing happens in the southern hemisphere. What ought to be south winds become south-east winds. So there are two belts of wind converging towards the equator from either side, but with a general trend to the west. (This is really only true over the oceans. Close to and over the continents, all sorts of other agencies are acting, which interfere with this regular circulation of air.) These regular winds,

blowing slantwise towards the equator from either side, are called trade winds. This is from an old use of the word trade, which means a steady course, though they are also good for trade in the ordinary sense. In the old days of sailing ships they were of the greatest importance; for men could be practically sure of a good sailing wind from a definite direction if they sailed their ship into the latitudes where the trade winds blow. Now that most ships use steam or oil the trade winds are not so directly useful. However, they still are important to us in other ways. But before we go on to explain why this is so, we must say a little more on the effects of the earth's spin upon the flow of wind and water.

The trade winds get turned towards the west because they are coming from nearer the poles, where the earth is not rotating so fast, and therefore get left behind by the quicker eastward movement of the earth's surface nearer the equator. If a wind was blowing in the opposite direction, towards the pole away from the equator, of course just the opposite would happen. It would start off with a high rate of movement towards the east, and would blow over regions where the surface was moving more slowly. So it would push on eastwards faster than they, and would get an easterly trend. A wind which starts blowing straight away from the equator has to become a south-west wind in the northern hemisphere, while in the southern hemisphere it has to become a north-west wind.

The hot air which is rising in the tropics must make a return current away from the equator to take the place of the air in the trade winds. One might expect that this high return current of warm air would not sink again until it reached the polar circles and got chilled, so that there would be a very simple air-circulation, with the

trade winds blowing near the surface of the earth, from close to the poles to close to the equator, and the return current of air high up blowing from near the equator to near the poles.

But as a matter of fact things are not nearly so simple. The high return currents, as they are blowing from a region of faster surface movement, must bend round towards the east, as we saw in the last paragraph. They bend right round until they are no longer getting any nearer the pole at all. So there is air always coming from near the equator and piling up around a particular zone of the earth's surface, which happens to be about a third of the way towards the poles. This piling up of the air cannot go on for ever. Air

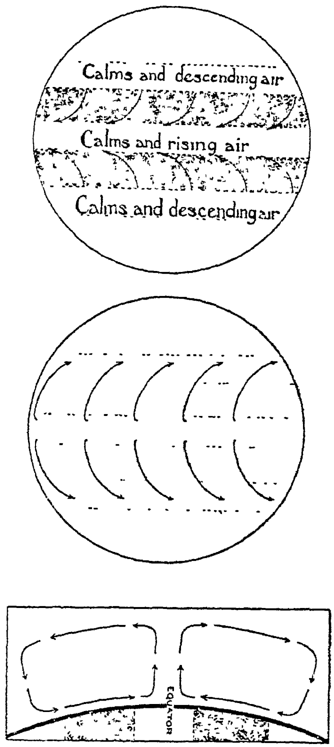


FIG. 17.—*A diagram of the air-circulation of the trade winds as it would be if the surface of the globe were all covered with sea. Above, the air-currents near the surface of the earth: these tend to blow to the west and form the trade winds. Centre, the air-currents high above the earth's surface: these tend to blow to the east. Below, the circulation as it would look from the side. The air is rising near the equator, moving towards the poles high up, sinking in the temperate zones, and moving towards the equator near the surface of the earth.*

has weight, and if it is piled up it must sink. So in these regions air will always be coming down again to near the surface of the earth. There it gets caught in the trade winds, the trade winds carry it to near the equator, and there it is heated and rises up again; and so a circulation is established. In the two belts beyond the trade winds, where the air is piled up, the air pressure at the surface of the earth will of course be greater, and the barometer will usually stand high; and where it is rising near the equator the air pressure will be lower than usual.

It would take too long to explain the air-circulation over the rest of the world, and the exact reasons for it. But we must mention one important fact, namely, that beyond the two high-pressure belts of descending air are two broad belts where the air pressure is on the whole low, where the prevailing winds are moist and from the west, and where storms and sudden changes of weather are frequent. It is in one of these belts that we live.

Further polewards the conditions change again, and the air pressure is rather high right inside the polar circles.

The World's Water Circulation

The same reasoning that we used about air moving over the face of the spinning globe can be applied to water moving from one part to another of the earth's surface. Thus ocean currents moving towards the equator will, like the trade winds, tend to move westwards, while those moving towards the poles will have an easterly trend.

We can now come back to the trade winds and their importance for us. As they are blowing slantwise towards the west from both sides, they will push the surface layers of the sea westwards along either side of the equator, making regular currents. The speed of the currents differs at

different seasons and in different places, but is generally between $\frac{1}{2}$ and 1 mile an hour. As most ships only go about 10 to 15 miles an hour, this will make a considerable difference to them.

When these equatorial currents come up against land, they are bent round towards the poles, and then, as they are coming from a region of faster surface movement, they will travel eastwards as well as polewards, as seen in the picture (Fig. 18).

Eventually, a good part of them comes back to where they started, to make up for the water driven westwards by the trade winds. Thus there is a sort of double slow whirlpool in each of the big oceans, one whirlpool to the north of the equator and one to the south. The exact way the currents flow will depend on many things. The shape of the land they flow against is one. Then there are other currents, such as the cold current which flows down from the arctic along the east coast of Canada, and these may interfere with the main whirlpool. Again, the system of trade winds and equatorial currents is really more complicated than we have described it: for instance, there is actually a belt of calms between the two trade winds. This is where the air is rising: so really there is an upward wind here. But a wind going straight up is no good for sailing, so from the point of view of the sailor, this is a region of calms (Figs. 16, 17). However, the general arrangement holds good.

The equatorial currents will of course be warm, so when they meet land and are turned towards the poles they will be carrying heat by convection to colder regions. The most famous example of this is the Gulf Stream or Florida Current. This is interesting for one thing because it is the fastest of all ocean currents. Between Florida and

the Bahamas it flows at an average rate of 3 miles an hour, and in some seasons may reach 5 miles an hour, which is quicker than the flow of a great river like the Mississippi over most of its course. In 1513, the Spanish explorer Ponce de Leon had the unpleasant experience of seeing one of his ships swept right away from the rest of his fleet by this current.

The chief importance of the Gulf Stream is its effect on the countries it reaches on the other side of the Atlantic, especially Great Britain and Ireland and Norway. These have a much milder climate than they have a right to expect from the latitude in which they are. If it were not for the warm current of the Gulf Stream, palms could not grow in Devon and Cornwall, Ireland could never have been called the Emerald Isle, and most of Norway would be covered with ice, just as Greenland is.

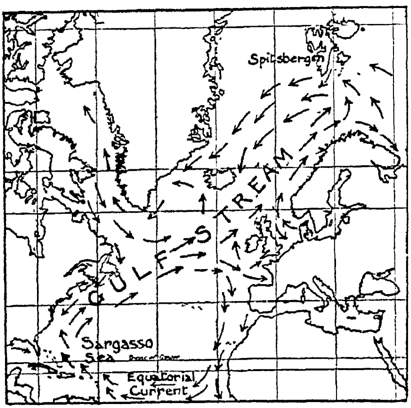


FIG. 18.—*The main ocean currents in the northern part of the Atlantic.*

What we have been saying explains why the climate must change as we go from the equator towards the poles, but also why we must not expect it to change in a perfectly regular way. Temperature is the most important fact for climate, though of course rainfall and other things are important too. The map at the end of the book shows how the average temperature does grade

off from near the equator towards the poles. But it also shows the influence of continents and of currents. For instance, the fact that there is an antarctic continent with huge masses of snow and ice on it makes places in the southern hemisphere colder than places in the corresponding latitude in the northern hemisphere. Again, the effect of the Gulf Stream in warming up north-western Europe shows very clearly, while the west coasts of South America and South Africa are colder than they ought to be, owing to cold currents from the south.

Water can circulate in two quite different ways over the face of the globe. Either it can remain as liquid water all the time, and circulate in the form of ocean currents; or else it can change from liquid to vapour and back to liquid again, evaporating out of the sea and moist land into the air, and then turning back into liquid and falling to the surface of the globe in the form of rain. Some of this rain falls on the sea. Some of what falls on land evaporates again, either directly or after being sucked out of the ground by plants and given off into the air through their leaves; and the rest finds its way back to the sea again in rivers.

After temperature, the most important fact for climate is the amount of rainfall. The amount of rainfall in any region depends to a considerable extent on whether the air, as it circulates, is moving upwards or downwards there. As heated air goes up, it passes into regions where the pressure is less, because there is less air weighing on it from above, as explained on p. 121 of "Simple Science"; and when the pressure is less, the air will expand. In the same book (p. 89) we mentioned that air gets hot when it is compressed, as, for instance, in a bicycle pump. The opposite is also true: when air

expands, it gets colder. The hotter air is, the more water vapour it can hold. So if hot moist air gets rapidly cooled by rising and expanding it will no longer be able to hold all its moisture, and some will turn into clouds, or actually fall as rain.

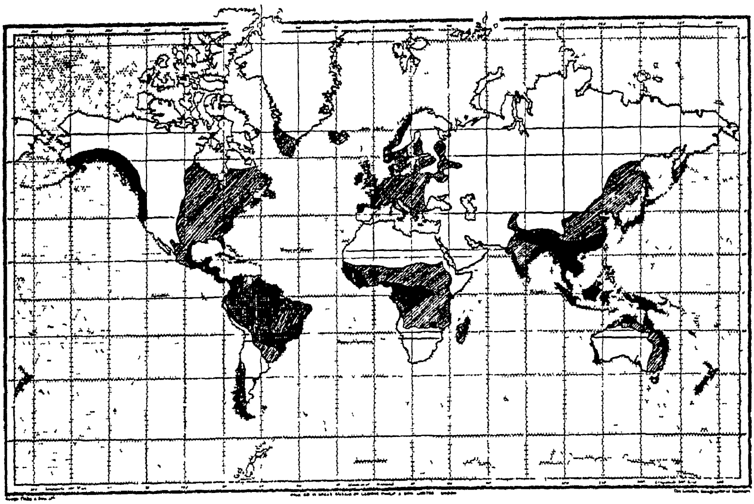


FIG. 19.—*The main rainfall zones of the world. The average rainfall during the year is over* 60 *inches in the dark areas of the land: it is between* 20 *and* 60 *inches in the medium shaded areas, and less than* 20 *inches in the white areas.*

It is because of this that clouds so often form in the afternoon of hot summer days. The sun heats the earth in the morning, the earth heats the air near it, the air begins to rise, and by the afternoon has cooled enough to produce clouds. Each cauliflower-like cloud is the cool top of a column of moist rising air.

It is because of this also that regions near the equator

have such heavy rain. Often for months on end it is fine every morning, and there is a heavy rainstorm every afternoon: as the hot moist air rises and cools it discharges its moisture as rain.

Just the opposite happens when air is descending from high up. The air gets compressed as it gets nearer the surface of the earth, and in getting compressed it becomes warmer. As it is warmer it can hold more water in the form of vapour, and so is unlikely to shed any as rain. That is why there is so little rain in the two dry belts on either side of the tropical zone. The air there has already given up a great deal of its moisture as rain when it ascended over the region of the equator. Then it begins to descend (Fig. 17), and so gets warmer and drier. No wonder there are deserts in these regions. In general there is more rain where the air-pressure is low and the air is rising, less where the air is descending and the air-pressure is high.

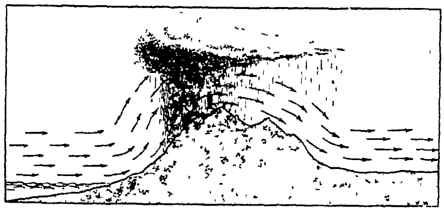


FIG. 20.—*Why rain falls on mountains near the sea. Winds from the sea are forced to rise. This makes the air expand: the expansion makes it cooler; and the cooling makes it shed some drops in the form of rain.*

Mountains are another very common cause of rain. Mountains make a barrier in the path of the wind, so that the moving air has to rise. In rising it gets cooled, and sheds its moisture as rain. This mountain rain is most abundant when the mountains stand close to a coast in the path of a sea wind laden with moisture it has picked up from the sea. The mountains called the Western

Ghats of India, which run close to the coast near Bombay, are a good example. During July, when a steady wind is blowing from the sea, there may be 50 inches of rain near the top of the Ghats, while on the Deccan plain to the east as little as 1 inch of rain may fall in the same time. Another example is the mountain country of North Wales and the Lake District. This stands in the path of the westerly winds from the Atlantic, and has a very great deal of rain (180 inches a year in one spot in the Lake District); while the east coast of England is much drier. Fig. 19 shows broadly how rainfall varies over the surface of the earth.

The Earth's Belts of Climate

Let us imagine ourselves taking an aeroplane journey from the North Pole to the equator, making notes of the kind of country we pass over. We should find it changed pretty regularly as we flew from north to south, and it would be interesting to try to understand the reasons for the change. The meridian of 25° east longitude would be a good one to fly along, and the summer would be the best time.

At first there is nothing to see but a flat expanse of ice with cracks in it. This is the frozen surface of the Arctic Ocean, cracked here and there by winds and currents. There would be no life at all for a long way, but after about 600 miles we should expect to see a few sea-birds and seals and perhaps a polar bear or so. Then we pass over the north-east corner of Spitsbergen. Most of this, we should see, is covered by an ice-cap, with glaciers flowing out from it into the sea. Round the edge of the ice-cap is a strip of barren plain with a few reindeer and foxes on it; no trees grow on it, only plants a few inches

high. Tundra is the name given to such arctic treeless lands.

After flying across the Barents Sea, where at first there would be floating ice-floes, and afterwards perhaps some fishing boats, we should strike another strip of tundra, about 100 miles wide, in Lapland. Here Lapps are to be seen, with their herds of reindeer. After this, there is a huge belt of forest to be crossed—nothing but fir-trees, with lakes and occasional clearings, and some bigger clearings and towns on the coast. Finally, just north of the Gulf of Finland, the dense forest gives place to more open country, with a good deal of woodland, but also a good deal of cultivation.

After the Gulf of Finland there comes well over 1,000 miles of land till the next sea is reached. As we go south, there are fewer fir-trees and more trees like oaks, which shed their leaves in winter; there are more fields of wheat and other crops, more villages, more people. Then we fly over the Carpathian Mountains, with rock peaks standing out of forest-clad slopes, to the fertile plain of the Danube, with a great deal of wheat growing on it, and then over the Balkan Mountains to the Ægean Sea.

Where there are mountains the climate is generally cooler and wetter than it would otherwise be; and as a matter of fact, on this route the Carpathian Mountains make us miss an interesting kind of country. If we had made our flight ten degrees further east, where there are no big mountains, we should have passed over the same belts of tundra, of fir forest, of scattered woodland with cultivation, but then, a couple of hundred miles north of the Black Sea, should have come to a great stretch of land which was almost treeless, except just along the rivers.

In the spring this would have been vivid green, but by the summer most of it would look yellowy-brown because there is so little rain that the grass turns brown very quickly. Such lands are called steppes, and there is a great belt of steppe extending eastwards for over 2,500 miles from the west end of the Black Sea.

The steppes are too dry for trees to grow, and often too dry to cultivate. So for the most part, especially to the east, they are inhabited only by wandering tribes with their flocks and herds, and there are hardly any towns or villages with people living a settled life.

But we must go on with our journey along the meridian of 25° E. We cross the corner of the Mediterranean Sea known as the Ægean, flying over many little islands, and eventually reach the north coast of Africa, just on the boundary between Egypt and the Italian colony of Libya.

Already on the north side of the Mediterranean there would be many changes to notice. The country is drier; there are a great many vineyards and plantations of olive-trees. But after crossing the 200 miles of sea between Crete and Africa, a big change is apparent. There is a narrow strip of fertile land, and then the country becomes much more barren, until a couple of hundred miles inland we are flying over a real desert. This is the east end of the Sahara, the biggest desert in the world. For over 1,000 miles we fly over the desert. Here and there is a green spot in the yellow-brown landscape. This is a patch of vegetation which grows round one of the few water-holes in the desert; such a green moist spot in the desert is called an oasis. But otherwise there is nothing to see but sand and bare rock, with perhaps a camel caravan now and then.

At last we emerge from the waste of sand, but even then there is another three hundred miles of dry, barren country to cross, with no trees but a few thorn-bushes, until the landscape becomes green again.

After the desert, at last we are in the tropical zone and begin to see negro people. But it is an upland country here, and at first is rather dry, with rolling grasslands and

FIG. 21.—*Life in the Arabian desert. A party of Arabs encamped at an oasis with their camels. A camel caravan is approaching across the sand-dunes.*

only scattered woods. However, there are forests along the river valleys, and gradually these forests grow bigger, and cover more and more of the landscape, until finally, about 400 miles north of the equator, the whole country is covered by trees, making a dense jungle, except where branches of the great Congo River shine through.

Eternal ice—tundra—fir forest—meadows and wood-land, with cornfield and vineyards—steppe, desert and

bush country—tropical forest—this is what we should see in our flight from pole to equator. These different kinds of country make belts, encircling the northern hemisphere. They are present in the southern hemisphere too, but there they are not so easy to follow, owing to the way the land is broken up south of the equator. But in Australia, for instance, it is easy to trace the tropical belt to the north, then the desert belt, then the belt of woodland and cultivation. In some places one or other of them is missing, as the steppe was on the meridian of 25° East; and the belts often run rather irregularly. This is due to some local cause, like a mountain range, or an arm of the sea: the general arrangement is regular enough. At the end of the book is a pictorial map showing the main life-zones of the world.

If we like we can simplify the picture still further, and group the different belts into four main zones of climate. There is the hot, wet, equatorial zone close to the equator. This is bordered on either side by a hot dry zone with scrub country, steppes and deserts in it. Beyond these dry zones come a pair of moist zones again, but this time not very hot. They include most of the temperate parts of the earth; towards the poles we can take as their boundary the place where trees will no longer grow. Beyond this, in the polar zones, the climate is drier again, but very cold. The polar zones are really caps spreading all round the two poles. Even in the sea, zones can be made out. For instance, the kinds of corals which make coral-reefs are only found in a broad belt round the equator. (There is a picture of a coral reef on p. 160 of "Simple Science.")

It is interesting, by the way, that we also find belts of climate on mountains. For instance, the great mountain-range called Ruwenzori, close to the equator in East

Africa, has its base clothed in dense equatorial forest. As you climb up the mountain the forest gets more like one in the temperate zone. At about 11,000 feet the forest ends, and you come out into grassland with scrub on it. Still higher up is moor country very like tundra, and finally vegetation ends and you come to the peaks of bare jagged rock sticking up out of snow and ice. These belts of climate on a mountain all depend on temperature: there is nothing to compare with the dry desert belt between the equatorial and the temperate zone.

This zoning of the world into belts of climate is, for us and the other animals and plants that live upon it, one of the most important facts about the earth. The map at the beginning of the book shows some of the main effects of climate upon life.

Life in the World's Cold Belts

Let us go back to our imaginary aeroplane journey from the pole to the equator (p. 40). Near the pole, the first main kind of country is a region of snow and ice. Very few plants can grow in this polar zone; for even where there is land, the soil, if it is not covered with snow all the year round, is uncovered only for a few months in the year. So most of the animals get their living from the sea. There are seals and walruses that live on fish and crabs and shell-fish, and polar bears that live on the seals. Sea-birds are the most abundant creatures. Their power of flight allows them to come north to breed in the arctic summer; and so soon as the food supplies are stopped by the sea freezing over, they can fly south again. Some of the birds have taken to water life so thoroughly that they use their wings to swim with, and cannot fly. The best known of these are the penguins,

but they are only found in the southern hemisphere. In the arctic, there used to be a kind of bird of the same sort, called the Great Auk; but it was mercilessly killed by sailors for food, and now there are no Great Auks left in the world—the whole species is extinct.

In "Simple Science," Part II, Chapter IV, we noted another feature of life in the arctic. In this region there are comparatively few cold-blooded animals. When we come to the human population of the arctic (there is none in the antarctic), we find that it, like the bird population, has to depend mainly on the sea. The best-known people of the arctic are the Eskimos, who live chiefly on seals. So difficult is human life in the arctic that the total number of Eskimos is only about 15,000—no more than the population of a smallish country town. There is a picture of an Eskimo hunting seals on p. 28.

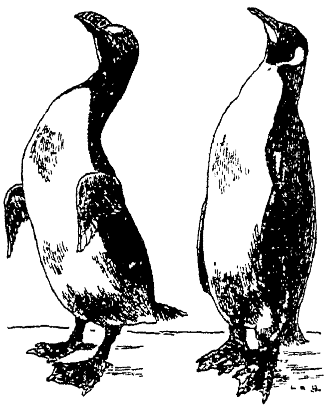


FIG. 22.—*Sea birds that cannot fly. Left, a great auk; right, a king penguin. The penguin swims with its wings, which are turned into flippers. The great auk swam with its feet.*

Next we come to the belt of tundra beyond the region of perpetual snow. The tundra is a great treeless moor. The reason that trees will not grow on it is the low average temperature of this belt of climate. The soil is always frozen solid to within a short distance of the surface, even in summer. So trees, which must send their roots deep into the soil if they are to nourish themselves and prevent

themselves from being blown over, can never grow there.

As a matter of fact, there are willows to be found in the arctic tundra. But instead of growing into trees or big shrubs, they creep along the ground, and so do not have any need for deep roots. In most parts of the tundra, the snow lasts until May or even to midsummer, and wintry conditions set in again by September, so that instead of four seasons, there are only two—summer and winter. Accordingly the active life of the tundra plants is confined to a few months in the year. But when the summer does come, life can be very intense. In parts of the Siberian tundra, large numbers of birds fly up from the south every year to nest. They feed on last year's berries, which have been preserved through the winter by the snow, and on the insects, which the warmth brings out in swarms. Mosquitoes are often so numerous on the tundra in summer that people have to wear veils on their hats to keep them off.

Reindeer and foxes are the chief big animals of the tundra, with musk-oxen (a small kind of ox, no bigger than a large sheep) in some parts. Life on the tundra is very hard for human beings, and most of them, like the Lapps, have to depend entirely on the reindeer which they have tamed. The Lapps are nomads, which means that they live a wandering life, moving their tents from place to place as their reindeer herds need fresh grazing. In this belt, again, the total number of human beings who now exist is very small. Some people, however, have suggested that reindeer and musk-oxen could be bred in large numbers there, and perhaps in days to come the tundra may furnish a considerable part of the world's supplies of meat.

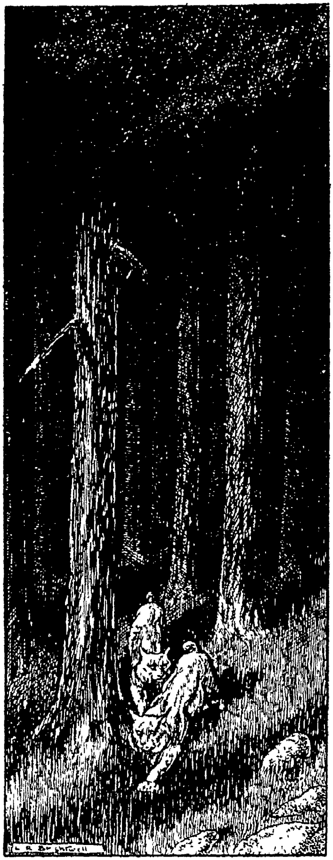


FIG. 23.—*In the northern evergreen forests of Canada. Little can grow in the shade of the fir-trees. A pair of lynxes are prowling through the forest.*

Next we come to the huge belt of forest that circles the northern hemisphere, all across Canada, Northern Europe, and Northern Asia. The forest begins where the soil is no longer frozen all the year round. Most of the trees, especially in the north, are cone-bearing trees such as spruce firs, which have needle-like leaves and stay green in winter as well as summer. Their needle-like leaves have very few stomata ("Simple Science," p. 356), and so let very little water escape. They also have much less surface in proportion to their volume than has a flat leaf. These characteristics, you can see, would be useful in dry climates, and as a matter of fact there are many kinds of evergreen cone-bearing trees which grow best in such conditions. The "Scotch fir" (which is really a pine) and other pines like the Austrian pine, are exam-

ples. But even when there is plenty of water in the soil the plant will not get much if the roots are not working actively; and this will happen when the soil is cold. So in cold countries, too, the trees have to take precautions against losing too much water through their leaves, and this is why you get trees with needle-leaves in the northern forests and high up on mountains. In winter, when the roots are so cold that they can hardly work at all, there is even less water for the tree. But as the leaves are in any case giving out so little water-vapour, the tree need not trouble to shed them as it would have to if they were big and flat, and with a great many stomata. So almost all the trees with needle-leaves are evergreens.

The firs in cold climates are almost all of "Christmas-tree" shape—that is to say, they have their branches sloping downwards, so as to let the winter's snow slip off easily, for otherwise they would break under the weight. In warm dry countries, the needle-leaved trees do not have to grow in this way; for instance, the umbrella pine, which is common in Italy, has a very different shape, as you can guess from its name.

In these northern forests the trees cast such a deep shade that hardly any other plants will grow under their canopy. Because of this, animal life there is rather scanty. There are rabbits and mice, porcupines and deer to be found, and creatures like lynxes, wolves and foxes which prey upon them. Several kinds of animals are adapted to live mainly in the trees, like the squirrels and the flesh-eating weasel-like martens, and there are various kinds of forest birds like woodpeckers.

Man, too, has a hard time of it in these gloomy woods, and lives largely by trapping animals for their furs. To-day, when wood is in such demand for paper, big sections

of the forests are being cut down, and the land thus cleared could be made available for cultivation. Where there is water power for electricity and cleared land for crops, we may expect to find civilization creeping northwards into what was once part of this forest belt.

The Temperate Lands and the Desert Belt

Most of the big civilisations of today are found in the next belt, between the gloomy fir forest and the useless desert. This, we have seen, is a region of changeable weather and many storms. But it is neither too hot nor too cold, neither too wet nor too dry. In most parts of it trees grow well, and in prehistoric times a great deal of its surface was covered with forest. The Weald of Kent, for instance, gets its name from a German word meaning forest, because, at the time of the Saxon invasions, a great forest still spread over it.

Most of the trees in this region are trees like oaks and elms and beeches, which shed their leaves in winter. The reason for this is that they live in places which are not very dry, so it is best for them to have broad leaves with plenty of stomata. They then can run a good current of water through themselves, which will mean that they can take up more salts with their roots, and build up food-material more quickly. At least, they can do this in the summer. But in the winter, when the ground is cold, and the roots do not work so well, there would not be enough water coming in to make up for what was being lost by the leaves in the form of water-vapour, and the plants would wilt and die. So to avoid this they shed their leaves before the weather grows too cold. It is only in the temperate belt that all the broad-leaved trees are bare in winter.

In the drier parts of the temperate belt, trees will not

grow except along the course of the rivers, and then you get big grassy plains, like the steppes of Russia, the prairies of Canada and the United States, or, in the southern hemisphere, the pampas of South America and the grasslands of Australia.

The sort of animals which are fitted to live on plains are either small burrowing creatures which can be safe underground (for there are no trees or thickets to escape into),

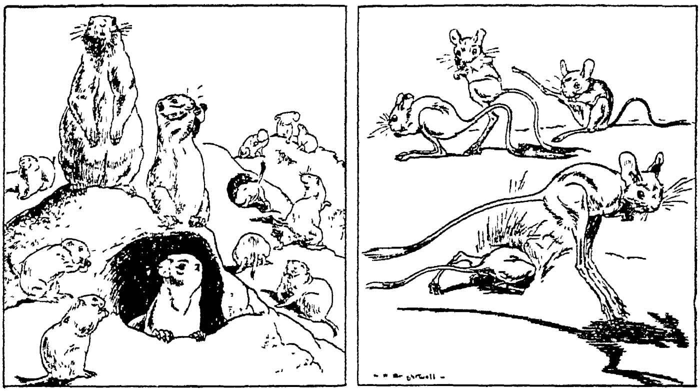


FIG. 24.—*Animals of the dry, bare lands. Left, marmots from the steppes. Right, ierboas from Arabia.*

or else big swift-running creatures. Marmots and prairie-dogs and ground-squirrels are examples of the first sort. Of the second kind, you will find wild horses and wild asses in the steppes, and kangaroos in Australia; and, before they were all but killed out, huge herds of bison (usually but wrongly called buffalo) and of pronghorn antelope wandered over the American prairies. Among small animals, the jerboas and jumping mice trust to speed rather than to burrowing underground. Some of the jer-

boas, though only the size of large mice, can cover the ground faster than a horse. Among insects, grasshoppers and locusts are very common on grassy plains.

There is a great variety of birds through the whole of this temperate belt, and all the best-known song-birds live here. Many of the birds migrate south in winter when insect food is scarce; and for the same reason many of the

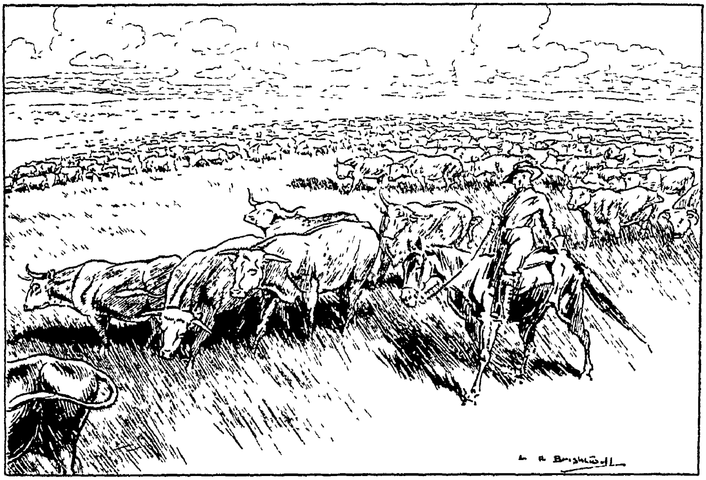


FIG. 25.—*A great cattle-ranch on the grass plains of South America.*

smaller four-footed animals, like dormice and marmots and ground-squirrels, go into the winter sleep we call hibernation.

In this belt, both in the wooded region and in the plains, man has made many changes. He has cut down the forests and turned them into farmland. He has planted wheat and maize and other crops both in the grasslands and in the clearings he has made in the woodlands. He has in-

troduced his own domestic grass-eating animals. The pampas of South America, for instance, is now covered with cattle destined to be turned into beef, and the grass-lands of Australia are grazed by millions of sheep.

In making these changes, man has almost or quite killed out many kinds of animals and birds. We have already spoken of the bison in America. In Britain, less than a thousand years ago, wolves were common, and organized hunts had to be undertaken when they became too dangerous. Deer, too, and wild boars and wild cats were abundant. This belt, in fact, is the region to which man, or at least the white man, is best suited; and it is the region which man has changed more than any other part of the world. Over all the fertile part of it he has got rid of most of the plants which grew there naturally and the wild animals that were adapted to the country, and has put in plants and animals which are useful to him.

As we get nearer and nearer to the belt of high air-pressure and low rainfall, the country gets drier, the trees give place to scattered scrub, agriculture grows less and less possible, until at length we reach the desert and find ourselves in a region as unfavourable to man as are the polar wastes.

In deserts you often find lakes of salt water, or thick crusts of solid salt. This is because there is not enough rain for the lakes to go on rising until they find an overflow. The amount of water that evaporates from them is as great as, or greater than, the amount which runs in, and so there is no river flowing out of them. There is a little salt in most soils, and water running in a stream takes up some of this in solution. So in a lake without an outlet, salt is all the time coming in, but none can get out, because when water evaporates, anything which it has dissolved in it

is left behind (Book I, Chapter VI). Accordingly, the lake gets saltier and saltier; and if the climate happens to get so dry that the lake dries right up, nothing is left of the lake but a white sheet of solid salt. The Dead Sea in Palestine is a famous example of these salty lakes, and the Great Salt Lake in Utah is another.

As regards life, the first characteristic of a desert is that plant life no longer manages to cover the ground. There is no canopy of trees or carpet of grass, but only scattered plants. The distance of one plant from its neighbours will vary with the conditions. In the worst deserts, like some parts of Arabia or the Sahara, there are no plants at all on the bare sand; but this is rare, and most deserts have a fair amount of scattered vegetation.

Of course these desert plants have to manage on much less water than plants in other situations, and must often go for long periods without any rain at all. Some of them arrange matters by living underground for most of the year, in the form of bulbs, and shooting up into leaf and flower as soon as it rains. In a couple of weeks they make all the food they need for the year, and exist in a dormant state all the rest of the time. In deserts which have a regular rainy season, the whole place is carpeted with beautiful flowers a few days after the first shower. Then, after the scanty rains are over, they retire underground, leaving a sandy barren waste once more.

Bigger plants, however, cannot do this. So they store big reserves of water inside themselves on which they can live through long droughts. Sometimes the water is stored in the swollen base of the stem. Dr. McDougall brought a shrub of this sort out of the Arizona desert and put it on the shelf in a museum. It lived for eleven years on the water stored inside itself, putting out leaves

every spring and shedding them again. This is the record. No other desert plant is known which has more than two or three years' reserve of water; compared with this it must be remembered that most plants that are not built to live in deserts will only survive a few days or hours without water.

FIG. 26. — *Desert plants. Cactuses in the American desert in Arizona. The man has cut off the top of a barrel cactus and is sucking up water from it.*

Most large desert plants have the whole of their stem and their branches swollen up to act as places for water storage. The best-known examples of this are the spiny swollen-looking plants called cactuses (or cacti), but many others do the same thing. In the American deserts there is one barrel-shaped sort of cactus on which the thirsty traveller can rely for a drink. He cuts the top off, mashes up the pulpy inside, and sucks up the juice through a straw. The biggest cactuses, like those seen in the picture, manage to grow to twenty and thirty feet high, in places where no other kind of tree can exist.

Of course, if desert plants are to store water properly, they must take steps against losing it by evaporation. One way of succeeding in this is to do without leaves, which means having no stomata. Cactuses, for instance, make all their food with their stems, which are green: they either have no leaves at all, or very tiny ones. Another way is to cover as much of the surface as possible with something which prevents water from evaporating quickly. Some plants do this by varnishing themselves, so to speak, with a waxy waterproof covering; there is an Indian gourd, called Benincasa, which produces so much wax for this purpose that the natives scrape it off and make candles with it. Corky bark also serves the same purpose; the corks we use come from the bark of the cork oak, which grows in dry situations. Still other plants, like the common mullein, grow a thick coat of woolly hairs on their leaves; this entangles water vapour and reduces evaporation.

Finally, as plant life is so scarce in deserts, it must be specially well protected against being eaten by animals, and so must be very prickly. Cactuses again are the best examples; they are covered with bunches of hairs as sharp as the finest needles. Many other plants in deserts and dry countries are provided with thorns, sometimes of enormous size.

The animals of deserts have as hard a time as the plants. Most of them are sandy-coloured to escape their enemies, and many of them have feet splayed out in some way to prevent them sinking in the sand, just as men put on snow-shoes or skis to go over soft snow. A great many make burrows to avoid the extreme heat of the sun. They are all adapted in some way or other to exist with very little water. Some, in this like certain kinds of desert plants,

live in a torpid state in burrows through the dry season, and only come out in the rains. Others, such as certain kinds of antelopes, never drink at all, but manage to get the water they need out of their food. Others again, like the cactuses among the plants, store water inside themselves. There is a kind of frog in the Australian desert which has a huge bladder in which almost pure water is stored. The natives, when they can find nothing else to drink, sometimes use this to quench their thirst.

The camel is the most important of all desert animals to man. Camels have broad splay feet which enable them to walk easily over soft sand in which a horse or a man or a motor-car would sink, and they can hold a store of water in their stomachs and can carry loads for three or four days without drink.

In desert countries like Mongolia, Arabia and the Sahara, human beings are as dependent on camels as the Eskimos are on seals or the Lapps on reindeer. In the desert parts of Arabia, for instance, human beings can only live where there is grazing for their camels. When the grazing is exhausted in one place, they pack their tents and belongings on to the camels' backs, and move to another. No settled civilization is possible, but only a wandering nomad existence, and the desert, unless it is artificially irrigated by having water brought to it in canals, can only support a small population. On page 43 there is a picture of a camel caravan in the desert.

Life near the Equator

Between the deserts and the rich tropical jungles there is generally another region of rather dry open plains, often dotted with scattered trees like a park. The best known

of such open park-like regions are in Africa. Here again, as on the temperate plain, the animals best suited to the conditions are grass-eaters which can run very fast. They generally live in herds, so that if one sees or smells danger the whole herd is warned.

In Africa, such animals can still be found in great

FIG. 27.—*Animal life on the African plains. An aeroplane has frightened the herds of game, and they are stampeding. There are zebras, ostriches, and several kinds of antelopes—gnu, Grant's gazelle, eland, sable, and oryx.*

numbers. The striped horses we know as zebras, buffaloes, rhinoceroses, the strange antelopes called gnus or wildebeest, many other kinds of antelopes, ostriches, and various kinds of wild pig roam the plains. The giraffe is another creature of this region, whose long neck specially fits him to feed on the leafy tops of thorn-trees which are out of reach of all the other animals. These

plant-eating animals are preyed upon by flesh-eaters such as lions, leopards, hyenas, and the fierce wild dogs which hunt in packs.

Finally, we reach the real equatorial forest. This is a product of tropical heat and moisture. Here there is so much water, and the air is so full of moisture that the difficulty is not how to keep water in the plant, but how to make enough of it escape to keep up a good current from the roots. Accordingly the trees have broad leaves with many stomata, and some plants have special glands on their leaves or branches for getting rid of drops of liquid water out of their insides into the air. There is no winter, so though the trees are broad-leaved, they need not all shed their leaves at one time, and the forest is green all the year round. Conditions are very favourable to plant growth, so not only do we find huge trees of many different kinds, but the trees themselves provide a home for many other kinds of plants. Creepers of various sorts hang from them, ferns and orchids grow on their branches. Many of these tree-growing plants have some of their roots hanging loose, and with them are able to suck moisture out of the air.

The biggest stretch of tropical forest in the world is in South America. Here we find many animals suited to life in trees. All the monkeys have prehensile tails (*prehensile* means able to catch hold of things), which they use as extra hands. High up in the trees the sloths travel slowly along, hanging upside-down from the branches. They are so well suited to life in the trees that they are completely unsuited to any other kind of life. On the ground, they can not stand upright, much less walk, for their feet are turned into hooks. They spend their whole life upside-down, though doubtless what is upside-down to us seems right way up to them. There are even

tree-porcupines and tree-anteaters with prehensile tails to help them to climb. There is an abundance of tree-frogs which stick to the leaves by suckers on their feet. Many kinds of snakes crawl about the branches and hardly ever come down to the ground: the boa-constrictors, which have prehensile tails, are the biggest and best known. There are some large bats which live on the fruits of the trees, as well as many fruit-eating birds, such as the funny-looking toucans whose big bills are used to pick and eat fruit. Some of these creatures live entirely on fruit. This is only possible in the tropics, where fruits of one kind or another are to be found all the year round, and not only in summer and autumn as with us. Climbing cats of various sorts, the biggest of which is the jaguar, prey on the other creatures. The frontispiece gives a picture of some of these animals and plants.

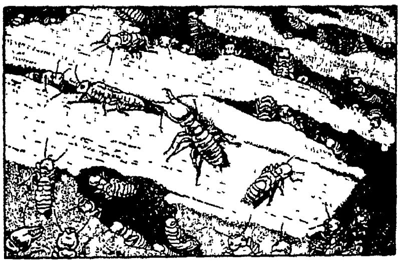


FIG. 28.—*Termites eating out a piece of wood. The ones with big heads and jaws are the soldiers.*

The little insects known as termites (often called white ants, though they are really not ants at all), which are able to digest wood, are very abundant, owing to the mass of fallen trees on which they can feed. Some of the spiders are enormous, and even catch small birds in their webs. Some animals of the tropical forest have grown folds of skin which act as parachutes to help them in jumping from tree to tree, and so save them from going down to the ground, where they would not feel at home. The best

known of these are the flying squirrels, which, however, are not found in South America; but there are also flying lemurs, flying phalangers, flying lizards, flying snakes, and flying frogs in tropical forests.

On the great plains, sight and smell are the senses on which most animals chiefly rely. But in the forests, where visibility is poor, and the trees break the force of the wind, hearing is the most important sense. So we find noisy creatures like howler monkeys and parrots; their

FIG. 29.—*Rice cultivation in Java. Women are planting rice, and men are ploughing. The fields are kept flooded.*

loud cries help the members of a flock from losing touch. And most of the animals have big ears.

Life is not easy for man in the tropical forest. It is always dark on the ground: the real surface of the forest is over a hundred feet up, where the crowns of the trees make a leafy carpet, and there is sunshine and fresh air. Everything grows so fast that even if a clearing is made it takes a great deal of labour to keep it from being quickly overgrown again. As there are thousands of kinds of insects, and as they can be active all the year round, any crops planted are very liable to be attacked by them.

So it comes about that in big tropical forest areas, as in South America and Central Africa, up till recently there were only scattered tribes of savages. It is only clearing on a big scale with the aid of modern machinery that can make such areas useful and productive for man.

Elsewhere in the tropics, where conditions are not so favourable to the growth of huge forests, a great deal of clearing has been done, and big populations can be supported. The island of Java, for instance, which is about as big as England and Wales, has more people per square mile. Rice and rubber, cocoa and palm-oil, sugar, spices and many fruits are products of the tropical regions.

A dark skin is an advantage in the tropics, because it keeps out certain rays of the sun which are harmful if the light is too intense; so we find that all people who naturally live in the tropics are black or brown. Many of them have very wide nostrils, like negroes and the Indians of tropical South America; this lets in air easily to the lungs, while the narrow noses of Eskimos, for instance, and most North American Indians will not let it pass so easily, so that the cold air of their countries gets warmed up as it passes in and cannot chill their lungs. The black races, like negroes, also have more sweat glands than white or yellow people. This helps to keep them cool in hot climates. Thus among men, as among animals, there are some kinds which are better suited to one sort of climate, some to another sort.

So we see that the climate belts decide a great deal of the life of the world. They decide whether animal and plant life shall be abundant or scanty, and what it shall be like. Climate has a great effect on man too. There are places like the arctic and the deserts where life is too scarce or too poor for men to live comfortably, and other

places, like the equatorial forest, where life is so luxuriant as to make things difficult for human beings. The two regions where man can be abundant and successful lie on either side of the desert belts. The cool stormy belts on the poleward side are the best suited to the civilisations of the white and yellow peoples, while brown and black men are better adapted to the hot countries nearer the equator, and live there in enormous numbers.

CHAPTER II

THE MAKE-UP AND HISTORY OF THE EARTH

The Make-Up of the Earth—The Earth has a Long History—Rock Layers and how they are Formed—Fossils—How Rock Layers are Folded and Tilted—Troughs and Domes in the Earth's Crust—Erosion and its Effects—The History of Life—Igneous Rocks

THE MAKE-UP OF THE EARTH

THE earth is a ball about 8,000 miles across. Concerning the great mass of its interior we know very little, but we know enough to be sure that it is quite different from the part we see at the surface. We know that its temperature is very high. As you go down in a mine the temperature rises steadily — on the average rather less than 1° C. for each 100 feet you go down — and it is certain that the bulk of the earth at more than 30 miles deep is at a very high temperature.

One proof of the high temperature inside the earth is given by volcanic eruptions. In the middle of a volcano is a sort of pipe or crack leading far down through the earth's crust to where the temperature is high enough to melt solid rocks. When the volcano erupts, some of this melted rock is forced up through the pipe and flows down the sides of the mountain, gradually cooling into what is called *lava*. The part of the volcano that we can see sticking up above the surface as a mountain is made of the lava and ashes that have been forced up through

the pipe in past ages. There is a picture of a volcano in eruption on p. 316 of "Simple Science."

The inside of the earth is also under enormous pressure —hundreds of thousands of times as great as the pressure of the atmosphere under which we live.

The earth consists of a thin lighter layer, or crust, as it is generally called, over a heavier mass inside. This has been proved in the following way:

Scientists have carried out experiments from which they are able to calculate the mass of the earth: from that, knowing its size, we can calculate its density ("Simple Science," p. 141). This turns out to be very high, about $5\frac{1}{2}$ grams per c.c.—i.e., the earth as a whole is $5\frac{1}{2}$ times as heavy as it would be if it were made of pure water. We also know, by breaking off pieces and making measurements in the laboratory, the density of the different kinds of rock that make up the surface layer of the earth; and this gives an average just about half as big as that for the earth as a whole.

The crust is very thin in comparison with the rest of the earth; its average thickness is only about ten miles, or one four-hundredth part of the earth's radius. The central mass which makes up much the greater part of the earth's bulk is very heavy and is probably made almost entirely of metals, chiefly iron. Outside this are other layers, lighter than the central core, but much heavier than the crust, and still with a good deal of metal in them.

Now if a mixture of a heavy metal, like iron, with earth or other impurities were heated in a furnace until it melted, the lighter substances would float up to the top to make a kind of scum or slag, as it is called, over the pure molten iron. If the whole were then allowed

to cool, this scum would cool down quicker than the iron, and turn into a crust on the top. Probably (though here again we cannot be certain) our earth was once a molten mixture something rather like the mixture in the furnace. The lighter parts would then float up to the surface, and so would be able to cool off more quickly and turn into the crust. The crust of the earth on which we live is like a thin film of light slag, with other layers of heavier slag below, and then in the middle a great metal ball.

But the separation of lighter from heavier materials does not stop here. Outside most of the crust is a layer of salt water, which has a density of just above 1 gram per cubic centimetre, and is therefore less than half as dense as the rock-crust. The amount of water in the sea is enough to make a layer more than a mile and a half thick over the whole of the earth. But owing to the fact that the earth's surface is not smooth but crumpled, parts of the crust stick up through the water layer to make the dry land. However, the sea actually covers $\frac{7}{10}$ of the whole surface of the earth, leaving only $\frac{3}{10}$ for the land.

Outside the surface of the sea and the land there is yet another layer of still lighter material, the air or atmosphere. Even where it is densest, close to the earth's surface, its density is only about one eight-hundredth of that of water, and the further we go from the earth's surface, the less dense does it become ("Simple Science," Chapter V). At twenty thousand feet, it is already less than half what it is at sea-level. It is impossible to say just how far up the atmosphere reaches, for it gradually gets less and less dense until it fades away into practically empty space. In Chapter I of Part III of "Simple Science" we spoke of the aurora borealis. It is known from the study of electricity that the lights which make up the aurora

borealis can only be produced where there is air at an extremely low pressure. We can also measure the height of auroras above the earth; this turns out to be from fifty to a hundred and fifty, or perhaps two hundred, miles. So there is a little air even at that height. But it is only a very little, and, as a matter of fact, $\frac{99}{100}$ of the gas of the atmosphere is within twenty miles of the earth's surface (Fig. 30).

Thus our planet consists of a number of layers of different kinds of matter one outside the other. It is rather like a round egg with several shells, and with the peculiarity that each layer or shell is less dense than what is inside it. The outermost shell, the atmosphere, is made of gas, and then comes the water layer, which constitutes most of what we are accustomed to call the surface of the globe. Next comes the thin solid crust of rock, which here and there sticks up through the water as dry land. Then there come thicker, heavier layers, and finally, corresponding to the yolk of the egg, there comes the great central mass, made mostly of metal, and very heavy. This central very heavy core is much the biggest part of the earth, taking in about three-quarters of its diameter. The crust is probably on the average only about 10 miles thick, and, as we have seen, there is very little atmosphere at more than 20 miles high. Even if we suppose the three outer layers, gas, water, and rock-crust taken together, to be 50 miles thick, this makes only about $\frac{1}{80}$ of the distance from the centre of the earth. In proportion, this is only about a tenth or an eighth as thick as the skin of an orange.

As for the parts of the earth in which living plants and animals can exist, they make a really very thin layer

close to the surface. A few men in aeroplanes have gone up about 8 miles, and in balloons about 12 miles; a few birds may sometimes go as high as Everest—nearly 6 miles; but there is hardly any life at more than 4 or 5 miles above sea-level. The deepest parts of the sea are

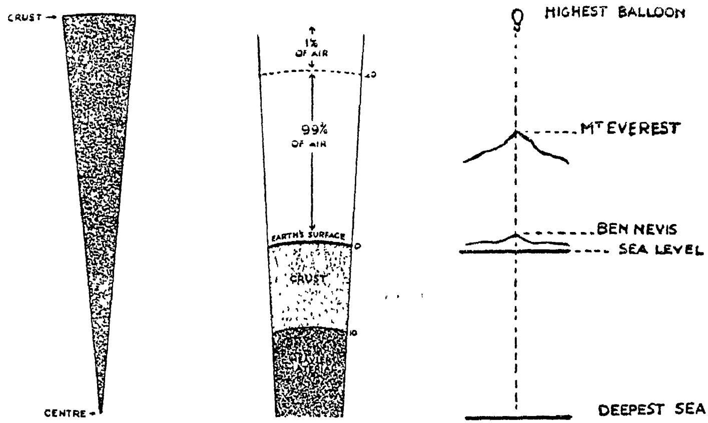


FIG. 30.—*The make-up of the earth. On the left, a diagram of a slice of the earth reaching from the surface to the centre, to show how thin the crust is in proportion. In the middle, the parts of the earth near the surface: the figures are miles above or below the surface. The crust is about* 10 *miles thick, and almost all the air is within* 20 *miles of the surface. On the right, a diagram to show the greatest height reached by man compared with the height of the highest mountain and the greatest depth known in the sea.*

less than 7 miles deep, and it is doubtful if there is much life there, though a good many kinds of animals are found as deep as 5 miles below the surface. So almost the whole of life is confined to a shell, part air, part earth, part water, about ten miles thick—only about one four-hundredth part of the earth's radius. That is to say that the rough-

nesses on the skin of an orange are bigger in proportion to its size than are the roughnesses on the earth's crust caused by the highest mountains and the deepest seas.

The Earth has a Long History

We talked about the air in "Simple Science," Part I (Chapter V). To-day, as we saw, it is made almost entirely of a mixture of the two gases oxygen and nitrogen, with a little water-vapour and a little carbon dioxide. It is worth remembering that in the early days of the earth's history the air probably contained much more water-vapour. For the surface of the earth was then probably at a temperature much higher than the boiling point of water, and if so there could have been no liquid water on the surface, but all the water in the world which was not imprisoned in the interior was in the atmosphere, in the form of steam. Gradually, however, as the earth cooled down, this steam or hot water-vapour was able to condense, and so all the hollows in the earth's surface became filled up with water, making the seas and the oceans.

The air of those days must have had many other substances in it in gas form besides oxygen and nitrogen; and this would mean that the water of the sea would have been salty from the beginning, for these substances would dissolve in the water, and some of them would make salts of different kinds there. But at any rate it must have been much less salty and more like fresh water than it is to-day. You can realise this by thinking what happens to all the rain that falls on the land. It trickles over and through the ground, and collects into streams and rivers which, with a few exceptions, end by flowing into the sea. Now, on its seaward course, all this water

will dissolve various soluble substances (such as salts—see Chapter V) out of the rocks and soil it passes over and carry them into the sea. The most abundant of these substances is salt—ordinary cooking salt, or sodium chloride. From the surface of the sea, water is all the time being evaporated by the heat of the sun into the air as water-vapour, but the salt, as we learnt in "Simple Science," Part I (Chapter VIII), cannot evaporate, and is left behind in the sea. Some of the water-vapour in the air, of course, condenses into rain, and this again either falls directly on to the sea, or if it falls on to the land, runs down into the sea in the form of rivers, and once more picks up salts on its course. The water is circulating all the time from the sea into the air and back again, but the salts get trapped in the sea. So the sea is all the time getting salter and salter.

This, by the way, helps us to realise how old the earth must be. We know that in every 100 pounds of sea water there are about 3½ pounds of salts. We can also make a fair estimate of the total amount of water in the sea. From this we can calculate the amount of salts in the sea. This is nearly 50,000 million million tons, or about 5 million cubic miles. You can get an idea of how much this is by thinking of all the land in the continent of Europe which is above sea-level: 5 million cubic miles is three times as big as this. This amount of salt would make a crust of solid salt 100 feet thick over the whole earth.

River water never contains more than tiny traces of salt, so even if only half the salt in the sea has been brought down by rivers, you can see that it must have been slowly collecting for millions of years to reach its present amount.

Any lake which has no outlet will get salty in the

same way. Sometimes it gets very salty, like the Dead Sea, which is one quarter salts—more than seven times as salty as ordinary sea water: it is so dense that people can float in it sitting up. The Great Salt Lake in Utah is nearly as salty. Sometimes rivers bring down special kinds of salts; for instance, the water of Lake Magadi in East Africa contains a great deal of soda, with very little cooking salt; the Dead Sea has more magnesium chloride than sodium chloride (cooking salt).

Round the edges of salt lakes layers of solid salts are often found. This means that the lake is gradually drying up and shrinking in size. If it dries up altogether a thick layer of salt will be left. Sometimes this salt is nearly pure sodium chloride, which is used as cooking salt; or it may be gypsum, which is calcium sulphate, and is used to make plaster of Paris; or other salts; or a mixture of several kinds of salts. Big layers of cooking salt are found in the earth's crust; in England, for instance, in parts of Cheshire and Worcestershire. Sometimes these salt beds are several hundred feet thick. They must have come from the drying up of seas or lakes in past ages, and then have been covered up by other rocks in a way we shall speak of later.

Though the layer inhabited by life is very thin, it is also very varied. One reason for this is the great difference of climate between different parts of the earth—some parts, like tropical forests, hot and moist; some, like deserts, hot and dry; some, like the polar regions, very cold; and others, like our own country, neither very hot nor very cold. We have spoken about different climates and the reasons for them in the first chapter.

Another quite different reason for the variety of the region inhabited by life is the fact that the crust of the

earth is made of a great many different kinds of rocks. The science which deals with all these different kinds of rocks is called geology; and, by the way, in geology the word *rock* means something a little different from what it does in ordinary language. In ordinary language rock means something particularly hard; but geologists use it to mean any kind of material which goes to make up the crust of the earth, whether it is very hard like granite, or very soft like clay, or in between like chalk.

Rock Layers and How They are Formed

What we have just been saying, about the saltiness of the sea, and about the thickness of solid salt layers in some places, shows that the earth must have had a very long history. We shall see that we cannot understand geology properly unless we think about the history of the rocks of the earth's crust as well as their nature and what they are made up of.

When you go on a journey you may pass over or through many different kinds of rock. A good example is the country between London and Bristol. Let us imagine we are making this journey in the train. At first the scenery is flat and dull. If you see a quarry in the earth it will probably be for gravel; under the gravel is tough clay. Then, a little after you have crossed the Thames at Maidenhead, the country will begin to get more hilly, and when the line goes through cuttings you will see that they are cut through white chalk. Then you come out on to a flat plain again, just before you turn west at Didcot, and see the steep hills behind you. They are the Berkshire Downs, and you have them on your left all the way to Swindon and beyond. They are all

made of chalk, as you can see by the quarries in them here and there, and the famous White Horse carved on the hills above Uffington.

The flat ground along which the train is running is all heavy clay. But after a time the line gets among hills again, and now when it goes through a cutting you will see that the rock is a hard limestone. These are the Cotswold Hills. Eventually they get so high that the train has to go through a long tunnel, and finally you come out again on a flat plain of clay covered with silt (silt is a deposit made of fine mud deposited by floods or by muddy rivers), through which the River Severn runs.

You would get the same sort of thing in other parts of the country, only the rocks would be different. For instance, the hills you go through near Tunbridge Wells on the way to Hastings are made of gritty sandstone; much of Derbyshire is hard limestone, while much of Devonshire is red sandstone; near Newcastle and in South Wales layers of coal are found at the surface.

The first question you will want to ask is: Why are the rocks different in different places? and the second is: How did they get where they are? We will see if we can answer these questions.

If you had looked closely at the rocks in the cuttings or quarries during your imaginary journey, you would have seen that they were arranged in definite layers: rocks of this kind are called *stratified* in geology, from the Latin word *stratum*, which means a covering or layer. This suggests that they were formed slowly, layer by layer, the bottom layers first, the top layer last. The obvious way in which a rock could be formed thus would be that the layers of material should have been laid

down by water. Materials that are laid down in this way are called deposits or sediments, and the rocks formed from them are sometimes called *sedimentary* instead of stratified.

You must have seen what happens after a rainstorm when a streamlet of muddy water runs into a puddle. While the water is running along it can carry the mud with it, but as soon as it reaches the puddle it spreads out like a fan, its movement is checked, and the mud sinks to the bottom. The fan-shaped deposit of mud will go on growing in height as layer after layer is added to it, until it is almost level with the surface of the puddle. It will also go on growing in length as mud is added to its end. Such a deposit of mud or sand dropped by running water when its movement is checked by its flowing into still water is called a delta, from its shape, which is like the Greek letter for D, written Δ, and called *delta*. Often round the borders of lakes you can see deltas made where streams run into the lake. Enormous deltas are formed where big rivers which are also very muddy flow into the sea. The Nile delta is one famous example: the Rhone and the Mississippi also have very big deltas. The Mississippi delta is growing out to sea quite rapidly: its end is now about 50 miles beyond the main coastline. The Mississippi brings down over 500 million tons of mud every year in its current (Fig. 31).

This is one way in which running water can deposit material in layers. Floods can also do this. If a river has overflowed its banks and there has been a flood, and you go and look at the meadows after the flood waters have gone, you will find them covered with a thin layer of silt, as fine mud brought down by water is called. In places where big muddy rivers flood their banks

pretty regularly these layers of silt may grow quite thick. The Nile is the most famous example: the fertile strip of land in the midst of desert on which the Egyptians live has been actually made by the river, as well as being watered by it every year when it floods. Such deposits are called alluvial. The plain of Lombardy in Italy is another example of alluvial land: it has been made by the River Po and other smaller rivers.

Then material can be laid down actually in the beds of rivers, in the shape of mud-banks and sand-banks. Much bigger sand-banks and mud-banks are formed in the sea, by the action of currents carrying the material and dropping it when their motion is checked. The material may be brought down by rivers and swept away from the rivers' mouths by strong currents before it can form a delta; or it may come from the sea eating away the land, as you can see in many parts of the English coast, such as Sheringham in Norfolk. Sea-currents may also deposit great beds of stones or shingle. The most famous example in England is the Chesil Bank near Portland, which is 18 miles long, 35 feet high, and nearly 200 yards wide; and most of Dungeness in Sussex is made of shingle.

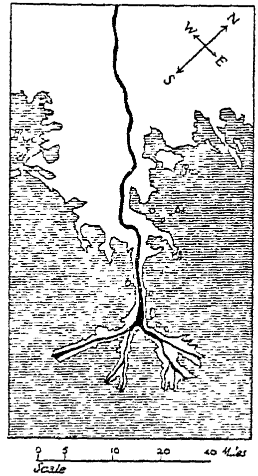


FIG. 31.—*The delta of the Mississippi river, which is slowly but steadily growing out into the sea.*

If conditions are favourable, the materials brought down by rivers, and also those produced by the sea eating

away the coast, will be laid down offshore all along the edge of a coast. This is a common way in which big sheets of sand or mud or shingle, extending for hundreds of miles, may be deposited.

A great deal of material may also be laid down as a result of ice-action. In some cold parts of the world, like Greenland and the Antarctic Continent, instead of there being separate glaciers of ice in the valleys, we find huge ice-sheets which cover large regions of the country. Glaciers and ice-sheets are made from the snow which falls in high, cold, mountainous regions, where it piles up into deep snow-fields. The weight of the layers above squeezes the lower layers together, turns them into ice, and forces the ice slowly outward and downwards until it reaches the sea, or a region warm enough to melt it. Both glaciers and ice-sheets grind away masses of material from the ground over which they pass; and they also carry with them much material which falls on them from any mountains at the side. Close to where they melt most of this material will be deposited. Now we know, as we shall explain at more length later (p. 100), that most of Britain north of the Thames once had a very different climate from to-day, and was covered with an ice-sheet of this sort. And many of the deposits in this country were laid down by the ice-sheet as it melted. Such deposits are called glacial drift (*glacial* means having to do with ice). The commonest form of glacial drift is boulder clay, which is made of very fine particles ground from rocks by the grinding action of moving ice; embedded in it are big angular stones and boulders, arranged anyhow, which originally fell on to the ice from neighbouring mountains. In some parts of Britain a great part of the surface of the country is covered with glacial drift, with sedimentary rock layers below.

FOSSILS

Besides materials which are laid down in this way in shallow water by rivers or currents, other materials may be deposited in deep water without the help of currents at all. Such material is largely made of the skeletons of the tiny animals and plants which live floating in the top layers of the sea. When they die, the skeletons, being heavier, sink slowly down to the bottom. Examples of such plants are the diatoms we spoke of in Chapter VII of Part I of "Simple Science"; they have flinty skeletons. Among tiny floating animals a very common one is a creature called Globigerina, with a skeleton of lime (Fig. 32).

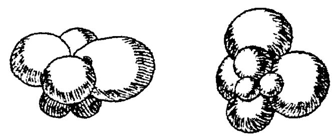


FIG. 32. — *Two views of the shell of Globigerina, very much magnified. Through the little holes, threads of living substance stick out during the animal's life, and with these it catches its food.*

Quite thick deposits can also be formed from the remains of animals or plants growing on the bottom. The best examples of these are corals. Sometimes great thicknesses of coral rock are found, with live corals at the top, growing on the remains of the limy skeletons of dead corals below.

When plants grow in swamps their dead leaves and branches fall to the bottom, and when, as happens sometimes, there is very little oxygen in the water of the swamps, they do not decay and rot away, but accumulate in thick masses. This is what is happening in peat-bogs. Peat is only the remains of the bog plants, sometimes mixed with a little earth. The layers of peat may be many feet thick, as you can see in parts of the country where peat is cut into blocks and used as fuel (see p. 162).

Layers of materials of different sorts are actually being deposited in all these different ways in the world at the present moment, and the same things must have been happening for millions of years. It is by these means that the stratified rocks of the earth's crust were formed. For instance, clays result from the deposition of mud by rivers or currents, sandstones from the depositions of sand. Chalk is formed in deep water by the slow downward drift of the tiny skeletons, whole or in bits, of little animals, mostly the Globigerina of which we spoke earlier; and coal is formed from the accumulation of plant remains in swamps.

Of course clay is tougher than mud, and sandstone harder than sand, while coal is much more solid than peat. These differences are due to the changes that have taken place in the deposits since they were first formed. For one thing, deposits may be exposed to great pressures—for instance, if they are being squashed down by hundreds of feet of new layers formed on top of them. Plant-remains in swamps with no oxygen in the water are changed in other ways, and gradually get converted into almost pure carbon, which is why coal is dense and black. Still other chemical changes may take place in sediments, cementing them together into hard masses: this happens in some kinds of limestones. But you can often see what the layer was originally made of. For instance, in sandstone you can see the separate grains of sand even when they have become cemented together to make a solid hard rock.

Bits of plants and animals may also remain to tell us what the deposits were originally like from which the rock layers were formed. Remains of leaves and branches are sometimes found in coal, showing that trees grew

near by. If you take a piece of chalk from a chalk quarry you can wash out from it fragments of the tiny shell-like skeletons of which it is composed; these are like the skeletons of animals which float near the surface of the sea, showing that chalk was formed at the bottom of an open sea.

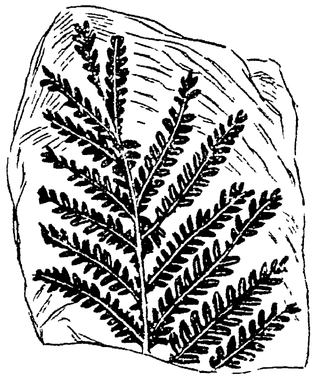


FIG. 33.—*Fossil remains of the leaf of a fern-like plant found in a piece of coal.*

Remains of animals or plants embedded in this way in rocks have actually been "turned into stone." In science this is called becoming fossilised, and the remains themselves are called fossils. Fossils may be big, like the leaves in coal, or microscopic, like the Globigerina in chalk.

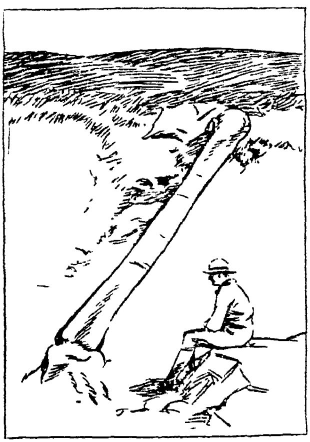


FIG. 34.—*A fossil. The hind-leg bone of a giant extinct reptile, rather like the Brontosaurus shown in Fig. 57, found in the side of a gulley in Wyoming.*

Fossils are found in most rocks which are arranged in layers. Bits of huge tree-trunks are sometimes found in the clay layers near coal seams, rooted upright in the original position in which they grew; fossil corals are common in the hills round Oxford; the pillars of Purbeck and Derby-

shire marble in many English cathedrals are full of fossils such as corals, sea-snails and sea-lilies. In the Old Red Sandstone whole fish are sometimes found fossil. Some clays and shales show fossil worm-holes and

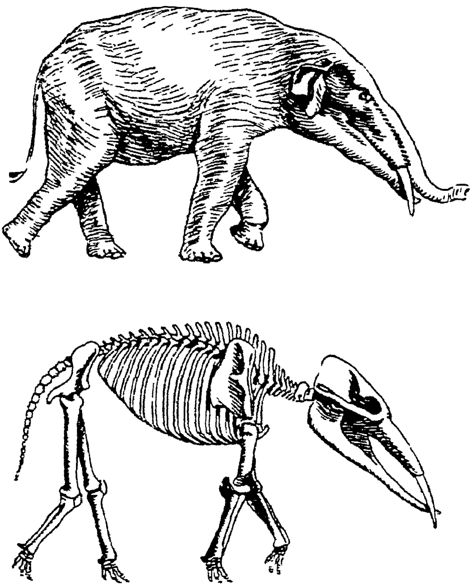


FIG. 35. — (*Below*) *The fossil skeleton of an extinct kind of elephant called a Mastodon, with a very long lower jaw.* (*Above*) *What the animal must have looked like when alive.*

even fossil rain-marks, while others bear the imprints of enormous feet. Sometimes the skeletons of extraordinary animals, quite unlike any animal known in the world to-day, are found fossil: there are many different kinds of these extinct creatures (*extinct* means that no

animals of the kind are alive any longer) in the Natural History Museum at South Kensington (Fig. 35).

Fig. 36. — *Fossil stumps of trees found in the coal-bearing rock layers near Sheffield.*

Until two or three hundred years ago fossils were a great puzzle to the people who troubled to think about them at all. The remains of extinct animals were

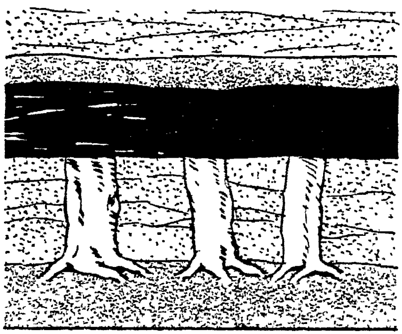


Fig. 37. — *To show how fossil tree-stumps are found in the layers under seams of coal. Originally the trees were rooted in the mud of the swamps in which were accumulated the leaves and other materials from which the coal was formed.*

one difficulty. For instance, when the skeleton of a creature which we now know to have been something

like a giant newt or salamander was found in Germany in 1726, it was supposed to be human, and to be the remains of one of the people drowned in the deluge described in the Bible. Then how was it possible that fossil oyster and scallop shells and fish skeletons and the remains of other marine animals and plants should be found on dry land? Again people tried to explain this by the story of the deluge: but this would not account for those which were found thousands of feet above sea-level in the Alps

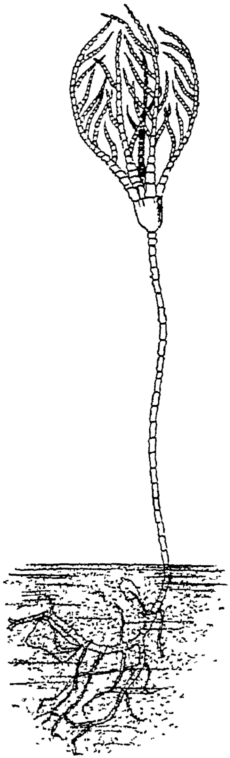


FIG. 38.—*A sea-lily growing. It is rather like a starfish, but fixed in the mud by a long jointed stalk.*

FIG. 39.—*A piece of Derbyshire limestone, polished to show the fossils it contains. Almost all of these are the stems of sea-lilies (see Fig. 38), cut across in various directions.*

and other mountains—there is not enough water in the world to make a flood as high as that. Some people

supposed they had nothing to do with plants and animals at all, but were just mineral formations, like crystals, or the moss-like arrangements you find in agates and other stones.

However, as fossils were carefully examined, it became clear that they must be the remains of creatures that were alive in times past. Fossil imprints of birds' feathers, fern leaves complete in every detail, extinct reptiles' eggs with a shell and the skeleton of the baby reptile inside, skulls and other bones as perfect as those you could get from an animal to-day, insect wings with all the veins showing — these and many other fossils could not possibly be anything else than what they seem. Fossils are thus very interesting, partly because they tell us in what sort of conditions the rock layer in which they were found was laid down, and partly because they prove that in bygone ages many kinds of animals and plants were alive which are now extinct.

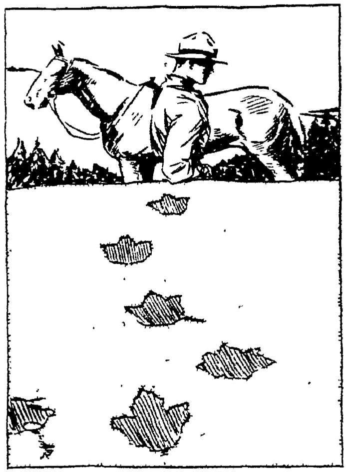


FIG. 40. — *Fossil footprints of an extinct animal (a giant reptile) found in a rock layer in Arizona. The horseman is leaning his elbow on the tilted slabs containing the footprints.*

How Rock Layers are Folded and Tilted

There still remains the difficulty of fossil seashells being found high up on dry land, and to explain this we must go back to an interesting fact about stratified rocks, which we have not mentioned so far. That is that the layers are not always flat, but may be tilted at an angle, as you can often see for yourselves in sea-cliffs or railway cuttings or quarries. Sometimes they are standing upright on edge, or even thrown into folds. This can

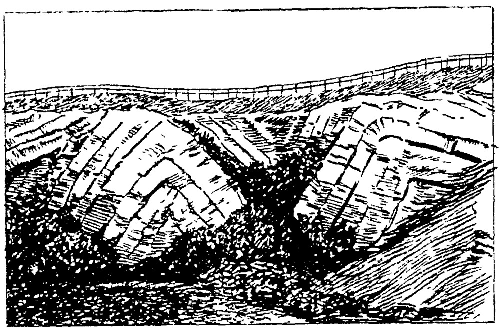


Fig. 41.—*Crumpled rock layers at Draughton, Yorks.*

only mean that at some time after the rocks were first laid down and hardened they have been tilted or folded by movements in the earth's crust (Fig. 41).

It is this which explains the presence of fossil sea-creatures in rocks high above sea-level. The rocks were first laid down layer by layer in the water where the scallops or fish lived, and then, ages later, were forced up above sea-level by movements in the earth's crust.

It would be too difficult to explain the causes of

all the different up-and-down movements of parts of the crust. Some of them, however, seem to be caused by shrinkage of the earth due to cooling (we explained in Chapter IV of Part II of "Simple Science" that almost all materials shrink or contract with cold). The shrinkage causes wrinkles and crumplings to form in the crust. You can easily see how this sort of thing happens if you think of a hollow rubber ball covered with a layer of stuff. If you made the ball smaller—for instance, if it was blown up tight and you then let out some of the air—the stuff would be thrown into little folds and crinkles. The foldings in the earth's crust are not formed in exactly the same way as these wrinkles, but the principle that shrinkage causes wrinkling is the same in both cases. The earth is so big that the wrinkles made by a very small amount of shrinkage will show as high mountain ranges.

Besides shrinking, big pieces of the crust may slowly rise or sink. In some parts of the world there is proof of such rising in the shape of what are called raised beaches—obvious sea-beaches with shingle or cliffs, but well above the level of the sea. There are many of these in Britain—at Torquay, for instance, and in parts of Scotland.

In other parts there are proofs of sinking. For instance, in some places on the English coasts, as at Leasowe, near Liverpool, you find submarine forests—the stumps of trees far below high water mark. This shows that a small change in level must have happened. Sometimes, however, you can be sure that bigger changes have taken place. For example, by soundings (that is, measuring the exact depth of the sea) it has been shown that river valleys may extend out under the sea to considerable depths. On

land, river valleys are slowly carved out by the effects of running water, as we shall describe more in detail later, but it would clearly be impossible for a valley to be made in this way on the bed of the sea. So the only explanation of submarine valleys of this sort is that they were originally made on dry land by rivers, and that later this part of the land sank so as to be below sea-level.

A very good example of such "drowned" river valleys is seen in the sea to the north of Norway. A big submarine valley can be traced about half-way between the mainland and the island of Spitsbergen, sloping westward to where the sea bottom goes very steeply down into deep water. This valley is formed by a number of tributary valleys which also can be traced on the sea bottom, as shown in the picture (Fig. 42). This means that originally all the sea bottom down to about 1,500 feet below the present sea-level was dry land; what are now the islands of Spitsbergen, Franz Josef Land, and Nova Zembla were the tops of mountains, and a great river drained the region, as shown in Fig. 43.

So far we have found out two main facts about stratified rocks. First, that they were laid down layer by layer in water, and afterwards gradually hardened. And secondly, that after being formed they may change their position, either by being just raised or lowered while remaining flat, or by being tilted at an angle or even folded or crumpled. But there are still other very interesting things about the stratified rocks which geologists have discovered. About the end of the eighteenth century an English surveyor called William Smith had the idea of making accurate notes on all the rocks he came across in his surveys: exactly where they were found; whether

they were in layers or not (we shall have something to say later about rocks which are not in layers); if so,

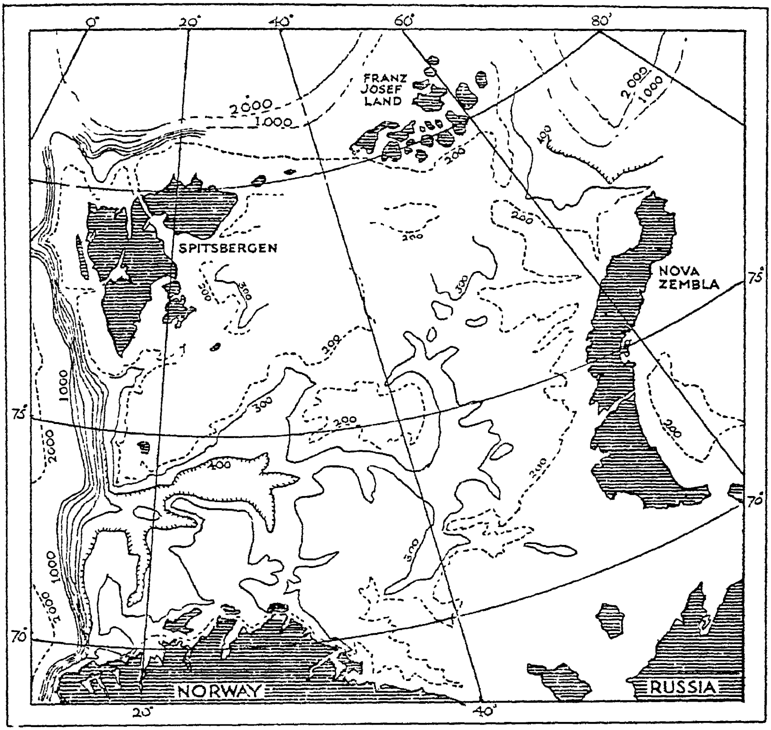


FIG. 42.—*The region north of Norway, showing the depth of the sea. The lines of depth are put in at each* 100 *metres between* 200 *and* 1,000 *metres deep. They show a big submarine valley,* 500 *metres below the surface at its deepest part, running westward, with several tributary valleys towards the east.*

exactly the angle at which the layers were tilted; and what fossils, if any, they contained.

One important practical thing that William Smith did was to make a map showing the way in which the

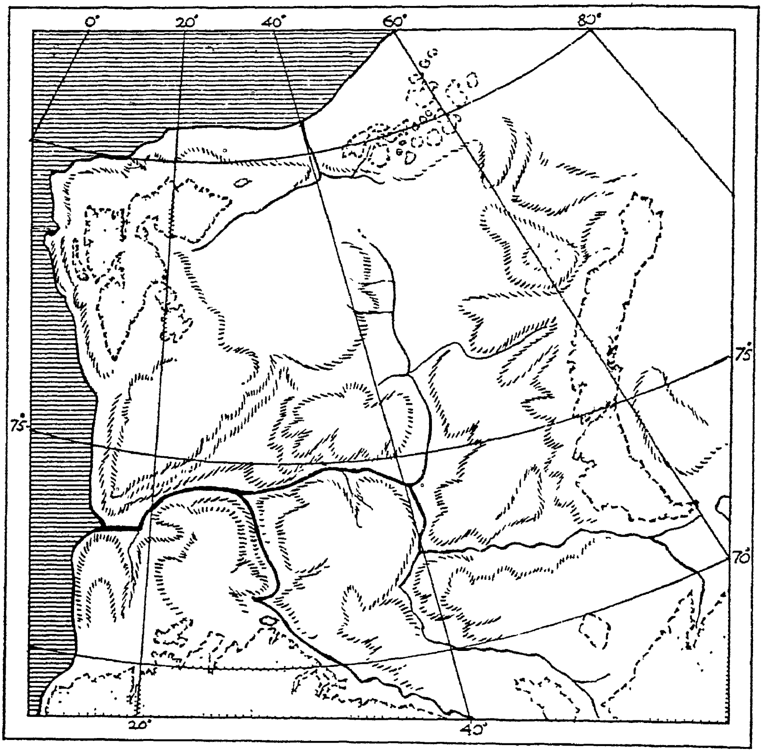


FIG. 43.—*The same region as that shown in Fig. 42, as it must have been when the land stood about 500 metres higher than to-day. A big river with several tributaries drained a region which is now the floor of the Barents Sea and the White Sea.*

different rocks were distributed over the face of England. A map of this sort is called a geological map. Other people

had had the idea before, but Smith was the first to carry it out really well. To-day, geological maps are widely used by people like mining engineers, oil experts, and water-surveyors to help them in looking for metals or oil or underground water.

He also made a great discovery about fossils. He showed that each particular layer of rock was marked out by containing certain special kinds of fossils not found in other layers, so that any layer could be identified by the fossils in it. To take an example, you probably know the beautiful fossil shells, coiled in a spiral, called Ammonites (which, as a matter of fact, were made by animals rather like a cuttlefish). These are only found in certain layers of rocks, and not in others. For instance, there are a great many of them in the clay layer near Lyme Regis in Dorset, but none in the different clay layer near London. And in the rocks where Ammonites are found, different kinds of Ammonites are found at different levels.

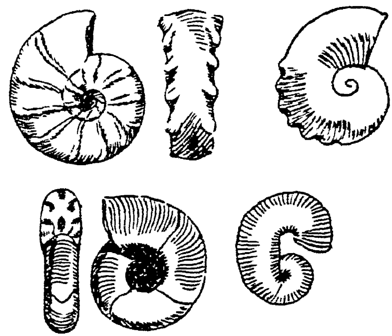


FIG. 44.—*Four different kinds of Ammonites. The two on the left are shown end-on as well as in surface view.*

Besides mapping the places in which different rocks are found at the surface, Smith also measured the angle at which they were tilted. Then the meaning of the map began to be clearer. We have explained how squeezing and crumpling of the earth's crust may cause the rock layers to become tilted or folded. The measurements

made by Smith and later geologists showed just *how* they had been disarranged. One simple thing which can happen is for a number of layers all to be tilted in one direction by the land rising in one region. Another is for the crust to be gently folded down so as to make a sort of trough or basin, and still another for it to be folded up to make an arch or flat dome.

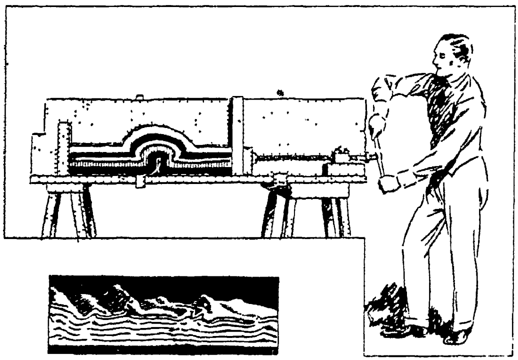


FIG. 45.—*An experiment to imitate the folding of rock-layers. Layers of plaster of Paris, clay, and loam were compressed between two boards. Inset, another experiment with clay layers thrown into a number of folds by being compressed to two-thirds of their original length.*

It is easy to understand this by arranging a number of layers of cloth on top of each other. If you then put a long strip of wood under the cloth near one edge, all the layers will be tilted up towards that edge; if you put it under the middle, you will get an arch; and if you put parallel strips along the two edges, you will get a trough. Similarly, if you put strips under all four edges, you will get a shallow basin or cup, while if you put a squarish block under the middle you will get a dome.

Or, instead of putting things under the layers of cloth, you can squeeze the layers sideways between boards. Squeezing between two boards will give you a series of troughs and arches if you press equally on both boards; or, if you press unequally, you get folds tilted towards one side. And with three or four boards pressed in different ways, you can get basins and domes of various shapes. Experiments can also be made with layers of clay and other substances, as shown in Fig. 45.

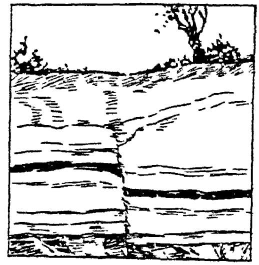


FIG. 46.—*A fault. There has been a break in the rock layers and the part on the right has sunk down a little. The black layer is a seam of coal.*

When rock-layers are bent too much, or exposed to pressure in other ways, they will crack and break; and when this happens, the layers on one side are generally shifted a little up, so that the layers on the two sides of the break no longer correspond, as shown in the picture (Fig. 46). Such a break is called a fault.

TROUGHS AND DOMES IN THE EARTH'S CRUST

Now we will look at some examples of these different ways of folding and tilting in rocks from different parts of England. The imaginary journey we took from London to Bristol gives a good example of simple tilting. After you get to the chalk, all the rock layers you pass through are slightly tilted up in the same general direction—towards the north-west. This must mean that after they were laid down the land to the north-west of them was pushed up. Later on we shall explain why the different

kinds of rock stop where they do—why, for instance, the chalk layer stops along the line of the Berkshire Downs, and does not continue on over the clay of the Vale of White Horse.

Then there is folding to make a trough or basin. There is a very good example of this in the country round London. North-west of London are the Chiltern Hills, all made of chalk. South of London are the North Downs,

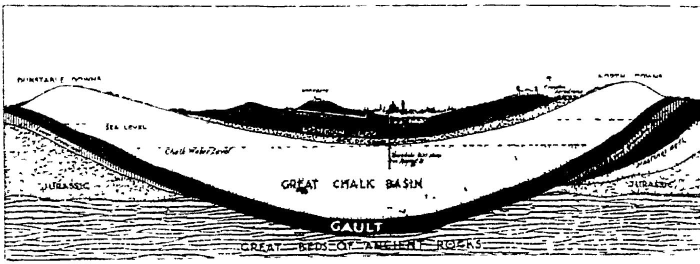


Fig. 47.—*The chalk trough under London. The rock layers are supposed to be cut through from North (on the left) to South. They are shown more tilted than in reality. The black layers are of clay, which will not let water pass through. The chalk basin is saturated with water up to the level of the dotted line. Gault is a kind of clay.*

(By kind permission of Messrs Le Grand, Sutcliff and Gell, Ltd., Southall.)

also made of chalk. Both have the same kinds of fossils in them, so they must be the same layer.

When you look at the tilt of the rocks you find that the layers of the Chilterns, as we have just seen, are tilted up towards a little north of north-west, while those of the North Downs are tilted in quite a different direction, towards the south. This looks as if the whole chalk layer in the region round London had been folded so as to make an irregular sort of trough, with its deepest part somewhere under London, and its edges rising on either

side to make the Chilterns and the North Downs. And this is actually so, as is shown by the fact that if you make a boring for a well in London, after going through a thick layer of clay you come to chalk.

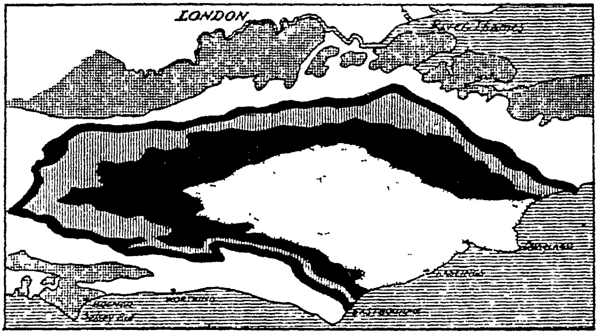
As a matter of fact, this trough of chalk is very important for London. It has clay lining it above, and underneath it is another layer of a different kind of clay. Now chalk is porous and can hold a good deal of water, but clay will not let any water through. So a good deal of the rain which falls on the chalk hills round London sinks down and fills the thick layers of chalk all through the trough: the chalk acts like a sponge absorbing water. The water cannot sink farther down because of the clay layer below, and it cannot rise to the surface because of the clay above. Also it is under pressure, because it is several hundred feet below the surface of the chalk hills. So when a boring is made and a pipe is let down through the top layer of clay into the chalk, the water rises in the pipe and can be used. In some troughs of this kind the pressure is so great that the water spouts right out at the surface. Sometimes, however, the water only rises a certain distance, and has to be pumped up the rest of the way: this is what happens in London. Wells of this sort, which tap underground water under pressure, are called artesian wells, from the region of France called Artois (the old name of which was Artesium) where they were first used in Europe. The deepest artesian wells are over a mile in depth, and the water in them is often hot, because it comes from so far below the surface. A great many buildings in the centre of London get their water from artesian wells on the premises. Sometimes water can be got even in deserts by means of artesian wells. This is the case in parts of the Sahara.

Next let us take an example of rocks being arched up to form a dome. There is a good example of this in the sandstone layers that make the hills of Ashdown Forest and St. Leonard's Forest, near Tunbridge Wells. On the side nearer London the rock layers are tilted so that they are higher towards the south, as shown in the picture (Fig. 48), but at the top of the hills they curve over and slope in the opposite direction—down towards the south, or, if you prefer it, up towards the north. All round the hills there is a plain of clay, called the Weald (from the Saxon word for forest, because of the thick forest of oak and ash trees that covered all of it in prehistoric times, and most of it until not many centuries ago). The sandstone layers slope downwards from the centre of the hills on all sides; but the slope towards the east and the west is much more gentle than towards the north and the south, so that the sandstone layers make a dome which is much longer in one direction than in the direction at right angles—rather like a very much flattened dish-cover.

This region also tells us some more interesting things about the history of the rock layers. As we said before, the North Downs are made of layers of chalk, which are tilted so as to slope up towards the south. Between them and Ashdown Forest comes a narrow valley with clay; then a ridge of sandy hills; and then the Weald plain of heavy clay. In all these the layers slope the same way as in the North Downs and the north side of Ashdown Forest—down towards the north.

We saw that on the south side of Ashdown Forest the layers slope down to the south. And to the south of this you get just the same sequence of layers as you had on the north side, only in reverse order and with reverse

slopes—Weald plain of heavy clay, then a sandstone ridge, then a narrow band of clay, and then a big layer



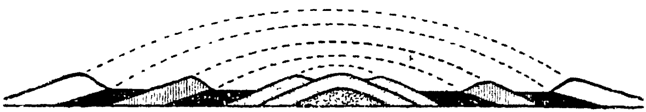


FIG. 48.—*Below, a diagram of the layers of which the Weald region is made, cut across from N.N.E. to S.S.W. The angle at which they are shown tilted is much greater than in reality. The side layers originally arched over the centre. Above, a geological map of the Weald region.*

Sandstone of Ashdown Forest region

Weald clay (broad band) and Gault clay (narrow band)

Sand and sandstone of Leith Hill, Hindhead, etc.

Chalk

Other deposits, including London Clay

of chalk in the form of the South Downs: and the layers of all these rocks slope down towards the south. Further-

more, the same fossils are found in the chalk of the North Downs and South Downs; in the Weald clay on either side of Ashdown Forest; and in the two narrow clay valleys and the two sandy ridges. So it appears that originally there was a continuous layer of chalk all the way across from the North to the South Downs, and that underneath the chalk there were other continuous layers of the other sorts of rocks—a thin clay bed, a sandy bed, a thick bed of heavy Weald clay, and underneath all these a layer of the sandstone which makes Ashdown Forest.

Then the whole region must have been arched up to make a sort of dome of flat dish-cover shape; and then the high middle part of all the layers must have been gradually broken up and washed away, until the only part left as an actual dome is the central bit which sticks up to make Ashdown Forest—and even that has had valleys cut into its sides. The dotted lines in the picture show how the different layers must have run originally, when the region was first gradually bulged up by squeezing from the sides. As clay, for instance, is softer than chalk, the Weald clay layer has been worn down more than the other layers until it is a flattish plain, while the chalk hills stick up like a rim round the whole region.

Erosion and its Effects

Perhaps you can hardly believe that such big changes can take place in the appearance of a country, or such enormous amounts of rock be worn away, or eroded as it is called, by the weather. But there is still another proof that this must have happened—namely, the course of the rivers in this part of the country. If you look at a map which shows the height of the country, you will

see that, although the chalk downs stand up like a rampart round the Weald plain, the rivers do not run down from them into the plain, but flow in the opposite direction, right through the chalk hills, in narrow steep valleys—almost gorges. The Wey at Guildford, the Mole at Box Hill, the Arun at Arundel are examples. If this part of the country had always been as it is now, there would be no possible way of understanding how these gorges were made. A river can only run down-hill, and yet the gorges have been cut down right through from the top of the chalk, hundreds of feet above the Weald plain. But if the region was once a single dome, with the chalk layer on top, everything becomes clear. The rivers started their course near the central top of the dome, and ran outwards down its slopes, carving deep valleys in the chalk. Then the central part of the chalk was worn away altogether, and gradually the edges of the hole in the chalk cover were eroded more and more until only the present rim of chalk was left. But while this was happening the valleys were being cut so deep that the rivers could still go on flowing outwards through them.

There are many other interesting things about the courses of rivers and the way they are influenced by geological structure, but there is only room here to mention one. If you look at a map of the Weald region, you will see that the course of the rivers is almost always either straight outwards from the centre of the dome, as where they run through the chalk gorges; or else at right angles to this, parallel with the ridge of the Downs. The gorge of the Wey in the chalk at Guildford is an example of the outward course; an example of the course of a river at right angles to the main slope is the little stream which

runs from near Dorking to join the Wey a few miles above Guildford.

Obviously, when the dome was first arched up, the first rivers to be formed would follow the tilt of the rock layers, and run outwards. Such rivers are called *consequent*, which means *following with*—they follow the original slope of the country. Later, however, when the softer layers underneath were exposed by erosion, side valleys would form in these. The rivers running in them are called *subsequent*, as they follow later. They flow close under a ridge of harder rock; and of course they will be at right angles to the original consequent rivers of which they are tributaries. As the rivers eat back into the hills new changes may take place; for instance, a subsequent tributary may become the main river and the original main river dwindle to a small tributary. But the two sorts of course will remain. In every region where there is a series of gently tilted or folded rock-layers you will find them—the rivers running down the original slope, and the rivers running at right angles to the original slope, along a softer layer at the foot of a ridge of harder rock.

This makes us realise what an enormous amount of land can be eaten away by wind and water, helped by the cracking caused by expansion with heat and contraction with cold, and the splitting caused by water getting into cracks and freezing, when it expands and exerts a great force.

This process is called *erosion*, which means eating away, or *denudation*, which means making bare.

There are a number of interesting things to notice about erosion and the way it works. In some parts of the world there is very little water; then rocks get split

up by heat and cold. They may also be eroded by strong winds blowing sand against their surface; this produces a very powerful effect (a sand-blast artificially blown out of a jet under pressure is often used to etch glass or metal). In such conditions the rocks break up into sand. Sometimes the sand moves slowly down the gullies on the sides of the mountains to make what one might call rivers of

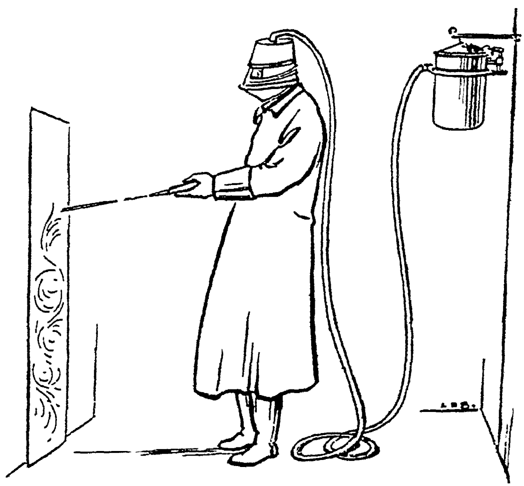


FIG. 49.—*Erosion by sand. A sand-blast being used to etch metal* (*as done in the open*). *The man has to be thoroughly protected.*

sand with fan-shaped sand deltas spread out on the plain, as you may see on the coasts of the Red Sea if you travel through the Suez Canal; or it is blown away by the wind and spread out to form great sandy expanses, often with high ridges or dunes of sand on them, as in the Sahara desert.

Then there is erosion by ice. Below glaciers, stones and

grit are rubbed along the rock under the huge pressure of the ice above, and scrape away great amounts of the rock into fine powder. If you go to Switzerland, you will see that the rivers which are formed by the melting ice and run out from under glaciers look like very soapy water because of all the finely powdered rock in the water. By these means, the bed of the glacier gets scooped out, and

FIG. 50.—*An effect of ice. Rocks in a country which has once been under an ice-sheet: stones and grit between the rock and the moving ice have produced numbers of more or less parallel scratches.*

the rock often gets scratched by sharp stones being dragged along under the ice.

In Britain there are no glaciers now, but in prehistoric times we know that there were plenty in Wales and Scotland and northern England. We can tell this by the scratches left on rocks by stones under ice, and also

in other ways. We can also see the special kinds of scooped-out valleys which the glaciers have left. They are steep-sided, but U-shaped in section, instead of V-shaped like the valleys eroded by liquid water (p. 105). Such valleys reach their deepest point before their end, and then rise again: the rise is in the place where the ice was not so thick, and therefore not so powerful in causing

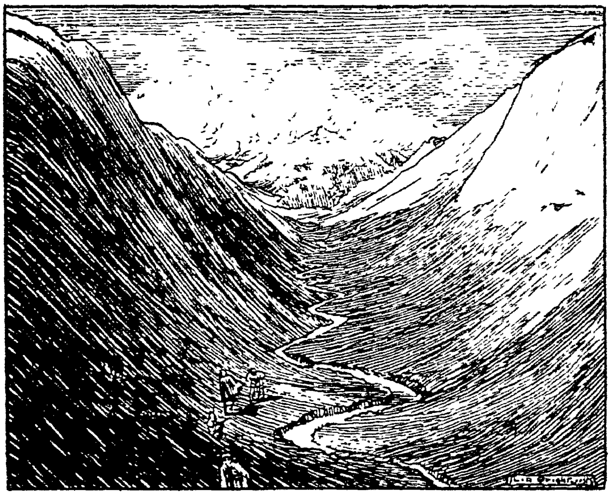


FIG. 51.—*A valley eroded by ice. A glacier once filled this valley up to the shoulder on either side. Such valleys are U-shaped in section, instead of V-shaped like valleys eroded by water.*

erosion. The lakes in the Lake District and the lochs of Scotland were largely shaped by glaciers: the rise at the lower end of the glacier valley acts as a dam, and some of the water flowing through the valley is held back above this dam to form a lake.

Where there are big ice-sheets instead of separate

glaciers (Chapter I), the erosion will be on a bigger scale; sometimes all the soil and surface layers have been ploughed up and carried away by the ice-sheet, as has happened in some parts of the Middle West in America.

Erosion, Geology and Scenery

But to-day in Britain erosion is almost entirely by water. One kind of water erosion is erosion by the sea. Sea-cliffs are due to the waves eating away the rock at the base of a hill; then the upper layers are no longer supported, and bits crack away and fall down. The bits that fall down are often soon broken up and carried away by the waves, so that the erosion continues eating into the land. The Needles are famous chalk rocks at the west end of the Isle of Wight. If you look at old pictures of them, you will see that they were much bigger: even within the last hundred years a great deal of them has been eroded away. Where the land is not very high and is made of not very hard material, sea erosion may be very rapid. Near Sheringham on the Norfolk coast, land on which houses and gardens stand is falling into the sea at the rate of several yards a year. Of course it is only in some places that the sea is eroding the land. At others, like Dungeness, it is adding to the land by depositing shingle or sand.

Another kind of water erosion is by running water. Rain falls on an area. Some of it flows down any slope there is, and carries some of the soil with it: you have never seen a runlet of rain going down a hillside that was not more or less muddy. The rest will seep down through the soil and rock, often dissolving substances as it goes. Most of the rain gets carried off in rivers: the surface water runs directly into the streams, while the water that has gone down into the soil comes out again in springs.

All rivers except very sluggish ones erode the country through which they flow. They are always cutting away parts of their banks, and also deepening their beds, thus making valleys or gorges.

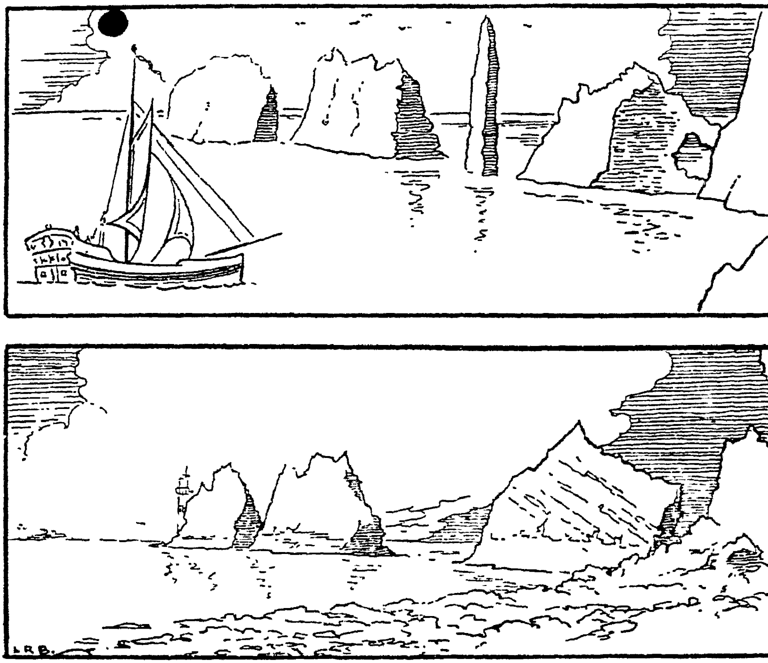


FIG. 52.—*Erosion is always going on. Two views of the Needles in the Isle of Wight. The upper one is from an old print of* 1782, *the lower from a recent photograph. The high pinnacle has entirely disappeared during the century and a half, and the other rocks have been somewhat reduced in size.*

Some of the most extraordinary effects of running water are found when land has been slowly lifted up

in such a way that rivers which take their source in high mountains, where there is plenty of rain, later run across

FIG. 53.—*A view in the Grand Canyon. This huge gorge, a mile deep, has been eroded by the river running in it.*

lower country where there is very little rain. Then they will cut down and down into the earth, making deep

gorges with precipitous sides and sharp edges. Steep-sided and sharp-edged gorges of this sort are called canyons. The most wonderful canyon is in Arizona, made by the Colorado river through a flat tableland where there is very little rain for most of the year, though heavy downfalls during a short season. It is nearly three hundred miles long, and at its deepest part (where it is called the Grand Canyon) is over a mile deep and ten miles wide on the average, though in other parts it is scarcely broader than deep. It has all been cut by the swift river at the bottom. There are many other canyons in Western America, and also a wonderful one made by the Blue Nile on its course from the mountains of Abyssinia to the dry plains below. The nearest approach to a canyon in England is the Bristol Gorge.

When a river passes through country with plenty of rainfall, the rain erodes the country on either side so that you no longer get a sharp-edged gorge, but a valley. In mountains where there is much rain, you will get swift torrents which will cut their bed down fast, and the rain and frost will erode the sides of the valley quickly too; thus you get deep valleys which go down and up steeply so as to be like a narrow V in cross-section. Among low hills the stream will not flow so rapidly, so that the deepening of the valley will not go on so fast. But the erosion due to rain will continue, and so the river valley will have a shape like a V with an open angle, as if flattened out. When the river is passing through a plain, its current will be very slow, and its cutting-power will be much reduced. Sometimes it may even be depositing some of the mud and sand it has brought down and filling up some of the flat trough in which it runs, so there will hardly be a valley at all, it will be so much flattened out. Also the river will

not have the power to cut straight, but will wind about in big bends and loops over the plain. Such bends are called meanders, from the winding river Meander in Asia Minor.

By the way, when you look at a river which flows in this winding fashion, you will often see proofs of its eroding power. As it flows round a bend, the current will flow more strongly against the concave side of the bend (concave as regards the bank), and less strongly on the convex side. Accordingly it will be cutting away the bank on the concave side so as to make a little cliff, and depositing silt or sand on the convex side, so that a little sandbank is built out here from the bank. The effect of this in the course of years will be that the bend will get more pronounced, as one bank gets cut back by soil being washed away and the other grows out by silt and sand being deposited. Eventually the neck of land between one bend and the next will get very narrow, and may be cut right through. Then the river will flow straight through in this new short cut; and the old bend will gradually get quite cut off from the river bed by the deposition of sandbanks. These remains of bends with water in them are called cut-offs or oxbows, and are evidence that rivers change their courses; there are some along the course of the Thames, and very big ones by the Mississippi in America.

A sluggish river like this may be flowing across a big plain that is almost flat for hundreds of miles on either side; or in quite a narrow plain between gentle hills. In the latter case, the plain is called a flood-plain. It is actually made by the silt carried down by the river and all its little tributary streams from the hills. The silt is deposited over the bottom of the valley when the river has been in flood.

But even if the plain is actually growing in this way, the erosion of the hills on either side will be going on all the time, since the rain which falls on them always carries some of the soil down to the bottom of the valley, where it is either deposited on the flat flood-plain, or else carried away to sea by the muddy river.

Thus we see that erosion is always helping to make a country flatter. It is carrying away material from mountains and hills, and piling it up at lower levels, either on flood-plains or in lakes or the sea. In steep mountains the erosion is quicker, and there is very little deposition; the flanks of the mountains are cut into deep gorges, and frost and sun and rain are eating away the ridges and the tops. The same process still goes on among hills, but as the river approaches sea-level, and its current gets slower, deposition begins to take place, so that the country gets flatter, not only by the wearing away of the hills, but also by the building up of the plains in the centre of the valleys.

All this, of course, takes place very very slowly. You can see very small results of erosion happening to-day, as when a river changes its bed a little, or a bit of a cliff falls, or a thin layer of silt is spread by a flood over a meadow. But if you remember that happenings like these have been going on for millions of years, you will realise that in the course of time they will add up to give very big changes, though in the space of a lifetime we cannot expect to notice much.

Perhaps you are thinking, Why, then, are there any hills or mountains in the world? Why have they not all been eroded away and flattened into plains in the course of the earth's long history? The answer is that new mountains are formed by the crumplings and other move-

ments of the earth's crust of which we have spoken. So in a sense mountains are born, grow old, and die, though it takes many millions of years to wear them down. In a thousand or even ten thousand years you would hardly notice any difference. Only when they are young—for mountains—are they high and steep. As they grow older they very gradually become more rounded and lower, because their tops are all eroded away; and eventually they will be denuded away till they are more or less flat, making a plain or a peneplain, which is the Latin for almost a plain.

So, too, river valleys change with time. When they are young they will be steep-sided, shaped like a narrow V in section, with a rapid stream at the bottom. After tens of thousands of years, when they have become old and mature, they will have changed into broad shallow troughs, with a sluggish river meandering through a flood-plain in the centre.

Now we must go back to the effect of erosion on different geological layers of rock.

When the layers have been tilted or arched, the wearing away of the top layers by erosion exposes others underneath. We have seen an example of this in the arched rocks south of London. Another example is found in the tilted layers between London and Bristol. Originally the chalk layer must have continued on above the others, far to the north-west. But erosion is more active in the higher parts, because there is more rain and more frost; so this high part of the chalk was all worn away, leaving only the low part towards the south-east, and exposing the clay and sand layers underneath.

As proof that this was originally so, sometimes you find out in the clay, plain little bits of the original chalk

layer that happen not to have been worn away, and stick up as hills. Such remains of the original overlying layer are called outliers. There is a very good example of a chalk outlier in Oxfordshire: an isolated chalk hill called Dorchester Clumps, with a prehistoric camp on the top, rises above the Thames out in the clay country, nearly five miles from the edge of the long chalk range that is here called the Chiltern Hills.

Then the clay and sand too get worn away in their higher parts, exposing the limestone layers that make the Cotswold Hills. The picture of the Weald (Fig. 48) will show you the sort of way in which this must have happened, though here the rock-layers are different.

One slope of the chalk downs is steep, the other very gentle. In the North Downs, for instance (Figs. 47, 48), the southern slope is the steep one. If you walk up the steep side, you pass all the separate little layers of which the chalk is made, from the oldest layer at the bottom to the newest layer at the top. On the other side they slope down very gently. If you walk up this long gentle slope, you will be walking all the time (except where little valleys have been formed) on the top layer of the chalk, and the angle of the slope represents the angle at which all the chalk layers have been tilted. A steep slope running along for miles, such as you get along the edge of the chalk downs, or along the north-west of the Cotswolds, is called an escarpment. The Cotswold Hills have a steep escarpment facing the Severn Valley.

So you see the face of the country is always changing —very slowly, but very steadily. When the first men came to England, Britain was still joined to the rest of Europe by dry land, and undoubtedly the hills must

have been higher than they are now, after many thousand years more of slow denudation.

Further, since the rock layers wear away at different rates, the erosion as well as the original tilting or folding

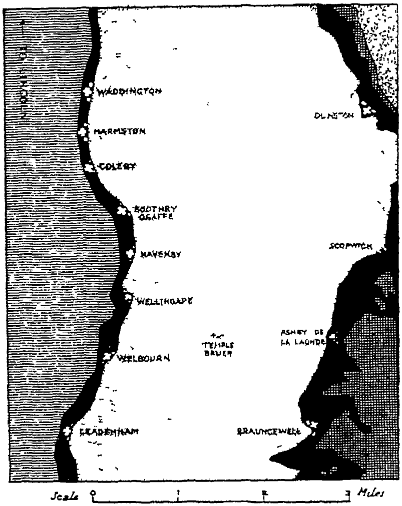


FIG. 54.—*A part of Lincolnshire to show the way in which the geological structure of the country has decided where the villages should be built. The villages are almost all close to the springs, which come out where a porous layer, a kind of limestone* , *touches other layers with clay in them* , *which will not let water pass, as shown in Fig.* 56.

has an effect on the scenery, for the soft layers will wear right down to flat plains while the harder layers will stand out as ridges. Different rocks also provide different soils, and this will mean different kinds of plants. For instance, you get beech-woods and short turf on the North Downs, oak-woods and rich meadows on the clay

plain of the Weald, while heather and woods of birches and pines are found on the sand ridge near Leith Hill or Hindhead. We shall have more to say in later chapters about different kinds of soil and their influence on plant life, but it is clear that in this way, too, scenery depends upon geology.

It is interesting to make a geological map of the country near where you live, and see what relation you

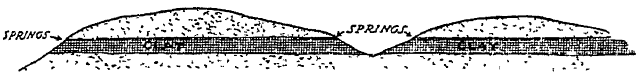


FIG. 55.—*One way in which springs are formed. Water falling on the surface of the ground will penetrate the porous layer (dotted) but cannot pass through the clay layer; so that it comes out where the top of the clay comes to the surface of the ground.*

can find between the scenery and the kind of rock and the tilt of the layers. Where the rivers run, the position

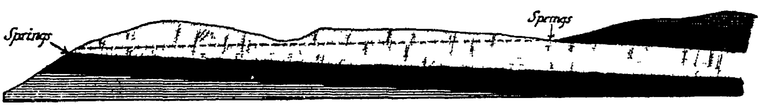


FIG. 56.—*Another way in which springs arise. In this case the rock layers are slightly tilted, and a porous limestone layer [dotted] is between two layers containing beds of clay [black], through which water will not readily pass. The porous layer is saturated with water up to the level of the dotted line. Springs come out above the lower clayey layer, and below the upper clayey layer. This is what is happening in the country shown in the map, Fig. 184. The different kinds of rock are tinted in the same way in the two pictures.*

and slope of the hills, the kind of vegetation—all these things depend upon the geology of the district. Geology also has an influence on human life. Springs flow out

of the ground where a porous layer, like chalk or sand, touches a layer like clay which will not let water through, as is shown in the pictures (Figs. 54 to 56), so you generally get villages built near the springs and not further up the slopes or further down in the plain. On barren sand you cannot expect to have a great many farms. Main roads will generally avoid marshes and swamps, and also very steep hills. And of course when the rocks contain valuable minerals, like coal, which are used in industry, big industrial towns will grow up in the neighbourhood. This is what you learn about in geography. But you cannot understand geography properly without knowing something about geology, as you will see if you make your geological map and study it carefully.

The History of Life

There is another very interesting idea that has grown out of William Smith's work. If a series of layers of rock are found one over the other, and they have been deposited by water, then it is quite clear that the bottom ones must have been deposited first, the top ones last. And if each layer has its own fossils, then the animals to which the fossil shells or bones belonged must have lived at different times: those found in the bottom layer must have lived further back in time than those in the top layer.

You can understand this easily by thinking of a very old city. People go to where there are ruins of ancient cities, like Troy, where the famous ten-years war which Homer wrote about took place between the Greeks and the Trojans, or Ur in Mesopotamia where Abraham lived,

and dig among the ruins to find out something about the history of the place. As they dig down they find layers of rubbish and earth mixed up with bricks from the buildings, bits of pottery and sometimes beautiful things like jewels or gold combs, or clay tablets with inscriptions on them. Often there are many layers, and the kind of pottery and so on will be different in different layers. Clearly the people who made the kind of pottery in the lowest layer of rubbish must have lived at the earliest period; and the people who lived there latest must have left the topmost layer of rubbish.

It is just the same with rock layers and fossils. So if you could arrange all the stratified rocks in their proper order, the whole set would be like a book, giving the history of the earth's crust for an enormous time: each main kind of rock would be like a chapter in the book, and each single little layer like a single page. And in this stone book you ought also to have the history of life on the earth for ages back, or at least of all the kinds of animals and plants whose skeletons easily become turned into fossils.

As a matter of fact, many of the pages of the stone book are missing, especially the earlier ones, because they have been weathered away by frost and sun and rain. Furthermore, many other pages can no longer be read to give us any information about the history of life, because they have been squashed and baked deep below the earth's surface under great pressures and high temperatures, so that all signs of fossils have been destroyed in them: clay, for instance, when baked and squashed in this way becomes ordinary slate, and limestone turns into marble. But even so, by piecing together all the facts, it has been possible to discover a great deal about

the history of animals and plants on the earth in times long past by studying the rock layers and their fossils.

For instance, in the earliest rocks there are no back-boned animals, and no land animals or land plants. Only in later rocks are fish fossils found, and later still fossils of land plants and the first air-breathing animals. These were amphibious animals of kinds that do not exist to-day, but were rather like very big newts (*amphibious* is the word used for creatures which live partly in water and partly on land, like frogs and newts). During this period most of the trees, too, were not a bit like any trees of to-day, but more like giant ferns, horse-tails and club-mosses.

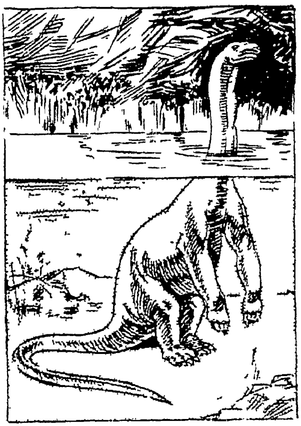


FIG. 57.—*A gigantic extinct animal. What the reptile Brontosaurus must have looked like. It was about* 100 *feet long and weighed about* 40 *tons; it probably lived in swamps and rivers.*

Some time after this there appeared the first back-boned animals able to live entirely on land instead of being amphibious. These were reptiles, which laid eggs and had scales but no hair (and were therefore, as we explained on p. 320 of "Simple Science," cold-blooded): but most of them are now extinct, and were very different from any reptiles alive to-day (Figs. 57, 58).

Some kinds had huge horns or strange bony armour; others grew to the biggest size ever reached by any four-footed creature; some of them took to the air and flew like bats, while others lived in the water and swam like whales. Some of these strange prehistoric animals are

shown in museums as they must have appeared when alive. This period in the earth's history went on for a long time: we can call it the Age of Reptiles. It was also the time when the Ammonites were plentiful in the seas.

At the end of the period when chalk was laid down, most of these strange reptiles died out, and only the snakes, lizards, crocodiles and tortoises survived. The Ammonites also became extinct. Meanwhile, rather before this time, the first flowers had appeared on the earth, and the first birds and mammals. The first bird, by the way, was a very odd-looking creature called *Archæopteryx*, which is Greek for "original winged animal." It had teeth, clawed fingers on its wings, and a long jointed tail. If it had not been for the fact that the imprint of its feathers has been beautifully preserved in the fossil, its skeleton could easily have been taken for that of a reptile (Fig. 59).

FIG. 58.—*An extinct animal. What the biggest of the flying reptiles or Pterosaurs must have looked like when alive. They had leathery wings, supported on the enormously enlarged "little" finger.*

After the main kinds of reptiles had died out, all sorts of very queer mammals appeared. Some had four horns, others a V-shaped horn on the nose. These later chapters of the stone book are very well preserved, so we can find some very interesting details of the history of life. For instance, in the very latest layers, all the horses are like those which live to-day, with a single hoof on each foot, and very long teeth with a complicated

grinding surface to chew up hard grasses. In the layers which date from before this, you find horses with one

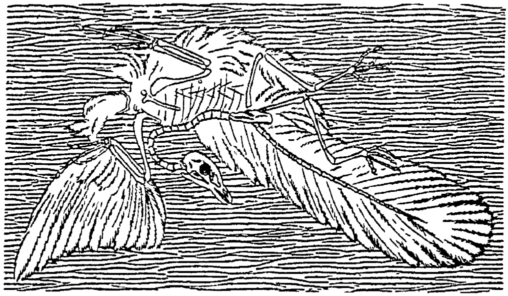


FIG. 59.—*The fossil remains of Archæopteryx, the first bird. It had teeth, claws on its wings, and a long jointed tail. The imprints of the feathers are well preserved.*

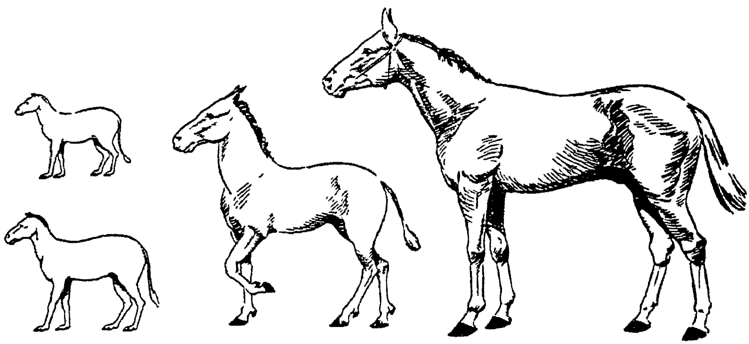


FIG. 60.—*The history of horses. On the right, a horse of to-day, with one toe (hoof) on each foot. Next to it, a horse from an earlier period, smaller in size, and with one big and two small toes on each foot. On the left, below, a horse-like animal with three equal-sized toes on each foot; and, above, the earliest known horse-like animal, very small and with four toes on the fore feet, three on the hind.*

main hoof and two little side toes with tiny hooves; earlier than this again, all the horses were smaller and

had three toes of about equal size, all with hooves, and their teeth were much shorter and with less complicated grinding arrangements. And before this again, the horses were no bigger than a moderate-sized dog, with four toes: if you only had these fossils to compare with the skeletons of horses to-day, you would not think they had anything to do with each other —in fact, you would not think that the little four-toed creatures belonged to the horse family at all. But the record is so complete that you have a continuous series from the one to the other. So there can be no doubt that the descendants of these original little four-toed animals gradually grew more and more horse-like, passing through a stage with three equal toes, and then one with one main toe and two small side ones, until the latest descendants had become real horses. As a matter of fact, if you look at a horse's skeleton, you will see on either side of the leg two very small bones attached to the main leg bones. These are called splint bones, and are all that is left of the two side toes. These changes took a very long time, probably about thirty million years.

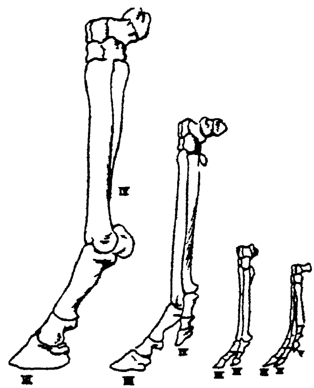


FIG. 61.—*The bones of the fore-foot in different horse-like animals. On the left, of a horse of today; the others are fossil bones, from the animals shown in Fig. 60. The numbers are the number of the toes. The little toe (V) disappeared early in the history of horses: in the modern horse, the toes IV and II are just small splints of bone.*

Many other kinds of animals and plants show this

same gradual change during their history—elephants, for instance, and camels, and whales. The earliest known skeletons of men are more like apes than men of to-day, having bigger teeth and jaws, less prominent chins and smaller brains.

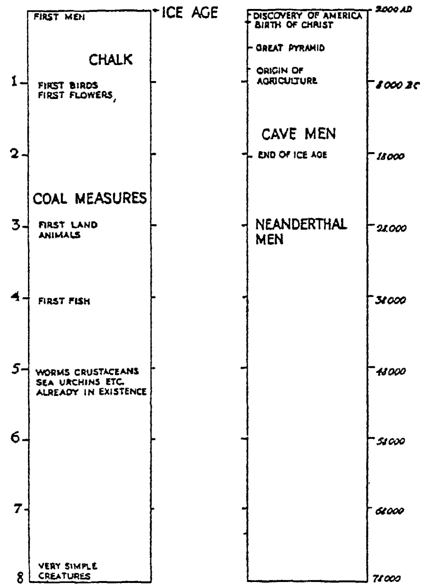


FIG. 62.—*Some events in the history of the earth. On the left, a scale taking in most of the history of life. Each unit represents* 100 *million years. On the right, a scale taking in the last* 80,000 *years; this represents only the top ten-thousandth part of the scale on the right.*

These changes have been very, very slow. The time taken in the earth's history was enormous, so enormous that it is hard even to imagine it. In the diagram (Fig. 62) are given some of the main events in the history of life as they have been pieced together from the fossils and the

rock layers. The rough dates for them are also given, though it would take too long to explain here how we know the actual ages of the different layers.

Before ending this chapter we must say a few words about rocks which are not stratified, since these make a very important part of the earth's crust. For one thing, many rocks which were originally laid down in layers have been changed through being buried deep under other layers of rock, and thus subjected to such great pressures and high temperatures that they have been altered out of all recognition. Sometimes all traces of layers have disappeared in these altered rocks: this has happened with marble, which is altered limestone. In other altered rocks, the original layers have disappeared, but the pressure has rearranged the materials in fresh layers, which generally run at an angle to the old ones. This is so with slate, which, as we mentioned earlier, is altered clay. The layers into which you can split slate have, as a rule, nothing to do with the original layers in which the clay was deposited as silt; they are due to the clay having been squashed under enormous pressure in a direction at an angle to the direction of the original layers. Layers of this sort are called shear-planes.

Igneous Rocks

But besides these altered stratified rocks there are still other rocks which have never been stratified. These are called igneous rocks, from the Latin word for fire, since instead of having been laid down in water, they owe their existence to heat, and have originally been melted by the high temperature deep inside the earth. There are two main kinds of igneous rocks. One kind has been erupted on to or near the surface of the earth

by volcanoes; the other has been squeezed up among the other rocks of the crust when liquid, and has cooled down and become solid without ever getting near the surface. If rocks of the latter kind are found at the surface to-day, it is because other rocks have been eroded away from above them.

The first kind are called volcanic rocks. They are being produced every time a volcano erupts, in the form of cinders, of pumice-stone, of sheets of lava, and of volcanic dust. Pumice-stone consists of melted rock which has suddenly been shot up into the air during an eruption. Where it came from it was under great pressure, and when it was shot out the gases dissolved in it expanded as the pressure suddenly grew less, and so, as it cooled and became solid, formed all the little cavities that make pumice-stone so light. Sometimes the eruption is so violent that it blows the rock into tiny bits, and these are shot out as volcanic dust. When the volcano of Krakatoa in the East Indies erupted in 1883, enormous quantities of volcanic dust were shot up into the air, and this was so fine that it floated in the air for months. Wonderful sunsets were seen in England some months after the eruption; these, it was shown, were due to this fine dust, which had drifted all round the world.

When thick sheets of lava cool, they sometimes turn into a series of six-sided columns of rock. This is due to very regular shrinking. Such rocks are called columnar. The commonest kind is seen in an igneous rock called basalt. There are famous examples of columnar basalt at the Giant's Causeway in Northern Ireland, and in Fingal's Cave on the Scottish island of Staffa. In some parts of the world, like the Deccan of India and in Western Scotland, layers of old lava extend over

thousands of square miles, and are hundreds of feet thick, showing that enormous volcanic eruptions must have gone on there in past ages. Porphyry is another rock which was once molten. Sometimes it is very beautiful, and is used like marble to decorate churches and fine buildings.

Sometimes volcanic eruptions force liquid molten rock into cracks in surrounding rock layers, where it

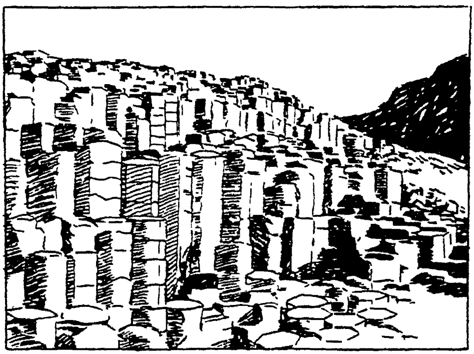


FIG. 63.—*Columnar basalt at the Giant's Causeway in Northern Ireland. The rock is made of pillar-like columns, mostly six-sided.*

cools and becomes solid lava. It often happens that the cracks are vertical; then when the rocks begin to be eroded away, the layer of lava is sometimes harder than the surrounding stratified rocks, and so after a time stands out like a wall. Such walls of old lava sticking up above the surrounding level are called dikes, and may run for miles across country. They are common in various parts of Scotland. So you see that there were once active volcanoes in Britain, though now there are none.

The other kinds of igneous rocks are called intrusive,

because they have been intruded or forced into the deeper part of the crust from below, and have cooled and become solid far from the surface. This means that they will have cooled more slowly. Further, slow cooling allows bigger crystals to form in the liquid mass as it solidifies, and so we can tell the intrusive rocks by their being made of fairly large crystals. The commonest rock of this kind is granite, and if you look at a piece of granite you will see that it is made of crystals of three kinds of material: felspar, which is greyish or reddish; quartz, which is translucent; and mica, which is in the form of bright little black plates.

FIG. 64.—*A dike. The dike is a layer of lava filling up a crack in other rock layers. As it is harder than they, it has worn away less, and now sticks up like a wall.*

FIG. 65.—*The polished surface of a piece of granite to show how it is made up of crystals of felspar (shown grey), mica (black) and quartz (white).*

Often enormous quantities of rock material have been melted and squeezed into the crust, forming huge masses of granite and other intrusive rocks. If the rock layers above are gradually weathered away, the granite will be exposed at the surface. Sometimes these granite masses are big enough to make large hills

or mountain ranges. Dartmoor in Devon is a great blob of granite, and so are many of the Grampian Mountains. Peterhead, near Aberdeen, is made of granite.

So we see that geology has a great many interesting things to tell us. It tells us of past volcanic eruptions, and of intrusions of melted rock. It tells what parts of the land were once under the sea, and how the crust of the earth was folded to form mountains and the mountains worn down to hills and plains. It teaches us how valleys are formed and how they change as they grow older. It tells us about kinds of animals and plants that no longer exist, and gives us knowledge of the past history of life on the earth. It helps us to understand the scenery of our country, and explains the difference between different kinds of soil. It tells us how enormously old the earth is, and shows us how the small and slow changes we can see going on in the world to-day may add up in the course of ages to give very big results.

CHAPTER III

THE CHEMISTRY OF LIFE

The Circulation of Matter through Life; The Carbon Cycle—Carbon and Power—The Nitrogen Cycle—The Phosphorus Cycle—The Wastefulness of Man

The Circulation of Matter through Life; The Carbon Cycle

SO much for the region in which life exists; now for something about the chemistry of this region, so far as life is concerned with it.

All life, human beings, animals, plants, and invisible bacteria alike, are made mainly of four common elements —carbon, oxygen, hydrogen and nitrogen. These together make up well over nine-tenths of the mass of the living parts of any animal or plant. But besides these there are other elements which are absolutely necessary for the construction of living matter, though only in very small amounts. The most important of these are phosphorus, calcium (the element characteristic of lime), iron, sulphur, magnesium, potassium and probably sodium and chlorine (the two elements which go to make up ordinary salt). This applies to the parts of animals which are actually living. Of course, there are other parts which are not alive, but are built up by the living parts to act as a skeleton for support or protection, like the hard material in our own bones, the external armour of crabs or beetles, the shells of snails and oysters, or the skeleton of corals: further, the skeleton often contains a great deal of the substances that are less abundant in the living parts, like calcium in corals, or calcium, magnesium and phosphorus in our

own bones, or they may contain substances not otherwise found in life, such as the flint (silica) which makes the skeleton of diatoms and of some sponges.

There are a few of these rarer substances which are particularly interesting, and we will come back to these; but for the moment we need only think of the four common elements—carbon, oxygen, hydrogen and nitrogen. These of course are compounded in all sorts of ways in the living body. The most complicated substances in living matter (and, indeed, the most complicated substances known to chemists) are the proteins ("Simple Science," p. 335), which contain all four of the elements just mentioned, often with others as well (such as sulphur), and have hundreds or even thousands of atoms in their molecules. There are also the sugars and starches (or carbohydrates) (see "Simple Science," Part III, Chapter VI), and the fats and oils. Then, besides a great variety of other organic substances, there are numerous salts—for instance, our blood contains common salt, or sodium chloride, and sodium bicarbonate (which is used in the baking powder for so-called "aerated bread" to give carbon dioxide); and, of course, a great deal of the hydrogen and oxygen in living bodies is just water—nearly two-thirds of the total weight in a human body, and ninety-nine per cent. in the body of a jellyfish.

However, we need not bother here with the exact nature of the substances built up inside living bodies, nor the details of the steps by which they are built up, especially as we already have said something about these points in plants, in "Simple Science," Part II, Chapter VI. Here we are concerned with the elements, and with the way in which animals and plants obtain them.

The first thing to remember is that there is what we may

call a circulation of these elements going on all the time. A living plant or animal is always taking in fresh materials, and also discharging them. Let us recall what happens in ourselves. First, oxygen. We take in a great deal of oxygen from the air that we breathe in; and in the air that we breathe out we discharge a corresponding amount, though then it is not free oxygen, but combined with carbon in the form of carbon dioxide. We also take in much oxygen in combined form in our food and drink. This is also the case with all the hydrogen we take in, which comes in many forms, in every kind of food and in drink. This hydrogen, and also the oxygen in food and drink, we get rid of in our breath, our sweat and our urine. Then there is carbon. All the carbon that we take in is in different substances in our food—sugars, starches, fats, oils and proteins; most that we discharge is again in the form of the carbon dioxide in our breath, though some is excreted in the urine. Fourthly, nitrogen. All the nitrogen we take in also comes from our food, as the nitrogen gas in the air is no use to us; but it comes only from the one kind of food called protein, such as egg-white, lean meat, or cheese. The nitrogen we discharge, on the other hand, all leaves the body in solution in the urine from our kidneys. This liquid also contains some of the salts that are discharged, and the rest of them are got rid of in the sweat. Water we take in with drink, and get rid of it by all three main methods of discharge—via the lungs in the moisture of the breath, via the kidneys in the urine, and via the skin in the sweat.

Thus the adventures of an atom of carbon, for instance, inside a human body are striking enough—coming into our system perhaps in a grain of starch in bread, circulating through the body as part of one of millions of molecules of sugar dissolved in the blood, used as fuel by one

of our muscles when it contracts, getting back into the blood as part of a molecule of dissolved carbon dioxide, and finally discharged from our lungs as carbonic acid gas. But it must have had equally interesting adventures before it gets into the body, and will be going to have more when it leaves the body again. What about this part of the story?

Let us trace out what may happen to carbon before it gets into our body or that of another animal. It must always enter in the form of food—sugar, starch, fat, oil, or protein: the carbon in the carbon dioxide in the air is useless to animals. The food may have formed part of the body of a plant—like the starch in your bread—or—like the fat in your meat—it may have formed part of the body of an animal. But if it was in the body of an animal, this animal will in the long run have had to get it from a plant. For instance, when you eat beef, this comes from an ox, and the ox got its carbon from grass. Or when you eat herring, the herring got its food materials by eating tiny shrimps and other small animals, but these ate the microscopic plants called diatoms—"the grass of the ocean."

All the carbon, therefore, which enters our body and the bodies of all animals comes eventually from some green plant. And the green plant gets its carbon from the reservoir of carbon dioxide gas which exists in the air.

So long as a man or any animal is alive, carbon is leaving its body to pass into the air or water in which it lives, in the shape of carbon dioxide. And the same is true for plants ("Simple Science," Part II, Chapter VI). If the plant or animal dies without being eaten, it decays, and again the carbon in it is mostly converted into carbon dioxide.

The Carbon Cycle

So the adventures of carbon are comparatively simple. It is always circulating through the bodies of plants and animals and back into lifeless matter. This circulation of an element through living creatures and out again into lifeless nature is generally called its "cycle." The carbon cycle runs something as follows. The storage of carbon

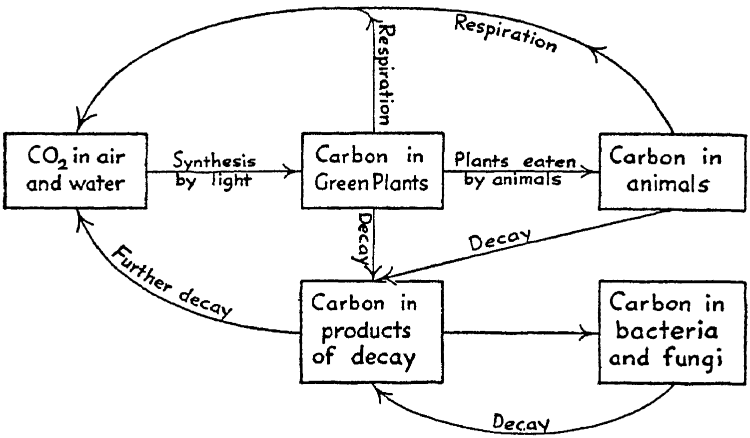


Fig. 66. — *The Carbon Cycle, omitting carbon locked up in coal, peat, oil, limestone, etc.*

on which plants can draw is in the form of carbon dioxide, either free gas in the air or else in a dissolved state in the water of rivers and lakes and the sea. This carbon dioxide is like a reservoir which can be tapped by green plants. They use it to build up sugar, starch and other substances. These substances are eventually broken down, and the carbon in them again enters the air or water as carbon dioxide—either directly, in the breathing of the

plants, or breathed out by animals which have eaten plants, or as the result of the decay of the plant or the animal.

The reservoir of carbon dioxide in the air is kept roughly constant, because the amount used up by green plants in building their leaves and stems and roots and seeds is about balanced by the amount breathed out by the plants themselves and by the animals which depend on them for food.

If an animal or plant is not eaten, but dies and rots away, then during the process of decay, some of the carbon may get into the bodies of plants which are not green, such as bacteria and fungi (toadstools and moulds). This is only a minor complication, and the carbon from them of course eventually comes back into the reservoir of carbon dioxide. But a more important complication is the fact that sometimes a mass of carbon is chemically locked up, so to speak, so that it has to stay out of the circulation so long as it is in that chemical form.

One of the forms in which carbon may be locked up is in coal and peat, which are produced when the remains of dead plants accumulate in places like marshes, where oxygen cannot get at them, and so there can be no slow combustion of the carbon in them to form carbon dioxide ("Simple Science," Part II, Chapter I).

The amount of carbon locked up in this form is enormous. It is estimated that the world still contains over 7 million million tons of coal. Most of this mass is just carbon: brown coals contain 50 to 70 per cent. of carbon, and in other coals the percentage runs up to over 90. So the world's coal must contain between 5 and 6 million million tons of carbon locked out of the circulation. The amount of carbon in the air is rather less than $\frac{3}{4}$ of a million million tons, and in carbon dioxide dissolved in the sea and fresh water somewhere about

15 million million. We know that the huge amount of coal in the earth has been gradually formed in the time since trees first appeared on our planet, which was about three hundred million years ago, and must all have come from the carbon dioxide in the air; so it is probable that

FIG. 67.—*Corals. Left, a stem of precious (red) coral; right, a brain-coral (Meandrina). In each case part of the coral is shown more highly magnified. The precious coral is a colony of polyps, each with tentacles surrounding a mouth. In the brain-coral the separate polyps are joined up in rows.*

before that time the atmosphere was richer in carbon dioxide than it is to-day.

Another form in which large amounts of carbon may be locked up for millions of years is mineral oil or petroleum. But the total amount of carbon in petroleum is much less than that in coal. Still another is limestone, which is calcium carbonate, with the formula $CaCO_3$. A good deal

of the huge amount of limestone found in nature is formed from the skeletons of animals or plants—corals are one example: the Dolomite mountains are the remains of big prehistoric coral reefs. Another example is provided by the tiny floating sea animal called Globigerina (p. 77); these make up the greater part of our chalk hills.

There are also sea-lilies and shellfish and certain kinds of seaweeds, which lock away carbon in their limy skeletons; and these skeletons may form large deposits. In addition, when rocks disintegrate or "weather" by being exposed to air and water, heat and cold (pp. 96, 157), chemical changes often take place which fix some of the carbon dioxide of the air in the form of carbonates.

In the course of time these accumulated reserves of carbon may be restored to the general circulation. Coal and oil exposed at the surface are gradually oxidised by the oxygen of the air, so that their carbon is turned back again into carbon dioxide gas. Solid deposits of calcium carbonate may get dissolved by water running over them (if the water contains carbon dioxide), and so become available for building skeletons of new animals and plants; if the water is acid, carbon dioxide is released from some of the carbonate, and can then be used by green plants for building living matter. All the time, huge amounts of carbon dioxide are being brought from the interior of the earth into the air or the surface waters by deep hot springs and volcanoes. It has been calculated that Cotopaxi, the big volcano in South America, discharges 2 million tons of carbon dioxide every year.

Carbon and Power

At the moment, however, the most active change is being caused by human beings. They are busy mining

coal, cutting peat, and pumping up oil in order to get power or heat by burning them. In the process of burning, of course, the carbon in the fuel is combined with oxygen to make carbon dioxide, and so gets restored to the general circulation.

Man has only used coal on a large scale for a little over a century, and oil for a little over half a century. At the present rate of consumption, the total supply will last only a few centuries more. For instance, at the present time, we use about 1,500 million tons of coal each year: at that rate the estimated coal supplies of the world would only last about 500 years. However, a great deal of the coal that is left is so deep below the surface that it would be very difficult and very expensive to mine it, so that for practical purposes the supply will probably not last so long. In countries where mining has been going on longest, like Britain, about a hundred years of mining at the present rate is likely to exhaust the readily-available part of the supply.

With oil, the situation is worse, because, although we only use about one-tenth as much oil as we do coal, for one thing the consumption of oil is going up faster than that of coal, and for another there is very much less oil than coal in existence. It is estimated that, even at the present rate of consumption, all the available oil in the earth's crust will be used up by the end of the present century, when a number of the children who read this book will still be alive. In less than a thousand years man is using up stores of carbon which took millions of years to accumulate.

This brings up another point. The reason why plants and animals take up carbon and other elements is because they require them to build their own living tissues, or

their own skeletons. Man on the other hand uses a great many elements for other reasons—to drive machinery, to produce warmth, to build houses and roads and machines, to fertilise crops, to make substances for himself like dyes and explosives and glass and cinema films and perfumes and metal tools.

In a way man is only doing what other animals do. He, like them, is utilising the resources of nature for his own ends, to further his own growth and development—but he has a new way of doing this. Besides doing as they do and taking in substances in his food to make the living machinery of his body and to produce energy there, he uses the elements of nature to generate energy and to make artificial machines and tools and substances to supplement those which his body produces naturally. The influence which he exerts in this way on the circulation of chemical elements in nature is very great. For instance, of the carbon which man uses, much the greater part is not for food, but serves to produce heat and power.

It might be supposed that the rapid destruction of the stores of carbon locked up in reserve during the past ages would lead to disaster: but the position is not really serious. For one thing, burning substances with carbon in them is not the only way of producing heat and power. There are plenty of other possible sources of energy (see "Simple Science," Part I, Chapter IV). We can be quite sure that as the stores of coal and oil begin to peter out, man will find ways of getting power cheaply from sources of energy which cannot be exhausted, but are available all the time, and are now just running to waste. Water-power and the sun's light and heat are the obvious sources of supply. The Russians have made a dam on the river Dnieper which gives 810,000 horse-power,

and other dams capable of generating even greater amounts of power are now being built in the United States and elsewhere. It is possible to get power out of the tides. There is a plan on foot at present to put a large dam or barrage across the estuary of the Severn, and then to get power from the inward flow of the rising tide and outward flow of the dammed-up water during the falling tide.

Engines have also been constructed for getting power from sunlight. It might also be possible to obtain power by building large numbers of windmills in broad open plains.

However, besides such methods, man could still get enormous amounts of carbon-containing fuel for burning even when all the reserves of coal and oil had gone. He could do this by making plants work for him. For instance, it is not difficult to make alcohol out of various plants and plant products, and when you have made it, you can use it instead of petrol to drive a motor—the engine has to be designed a little differently, but that is all. Already alcohol is used, mixed with petrol, to drive motor-buses in France and elsewhere. It can be made cheaply on a large scale out of almost any sugary or starchy substance. At the moment the usual raw materials are potatoes, the waste from paper factories, and a cheap form of black treacle or molasses. There are special tank steamers built to carry this sort of molasses from where it is made out of sugar-cane to where it is turned into fuel in alcohol factories. Plants can grow very fast all the year round in the hot warm regions near the equator; so eventually, we may expect, men will use these regions to grow plants for fuel, and much of what is now tropical jungle, in Africa, South America, and Asia, will be covered with

quick-growing crops destined to be turned into power alcohol. Although chemists have known for a long time how to make alcohol out of plant products, it is only quite recently that they have discovered how to make it cheaply. So possibly they will in time also discover methods for the cheap production of other carbon-containing fuels, such as benzol or petrol, from plants.

In any case, the amount of carbon dioxide in the atmosphere and surface waters of the earth is more than enough to supply the needs of all the green plants that could possibly be crowded on to the earth's surface; and the fuel made from the plants would soon be burnt and the carbon in it turned into carbon dioxide again and sent back into the reservoir of the atmosphere. So with carbon there is no danger of any shortage, since the final form in which it appears, after it has been used by animals for food or by man for fuel, is carbon dioxide, on which green plants can at once get busy, and so start the circulation going again. The circulation is a closed one, with no permanent leak in it.

The Nitrogen Cycle

Next we had better take nitrogen and its circulation or cycle. The nitrogen cycle is more complicated than the carbon cycle, but also in some ways more interesting.

As with carbon, so with nitrogen: it is the green plants which take up from lifeless matter most of the nitrogen used by life. They suck it up—either by their roots if they are land plants, or over the whole of their surface if they are water plants entirely immersed in water. They suck it up in solution, in the form of the simple salts called nitrates. (See "Simple Science," Part II, Chapter VI.)

In the bodies of the plants it is built up into very com-

plicated chemical substances such as proteins, and these are the source of supply of nitrogen. Proteins are composed of simpler substances called *amino-acids.* All of these have nitrogen in them. The simplest is glycine, which has the formula $CH_2(NH_2).COOH$. Some of them have many more carbon atoms than this, and some have sulphur as well, like cystine from wool. In proteins, the amino-acids are arranged in long chains or strings of amino-acids joined end to end. This is rather like the way in which, as we saw in "Simple Science," Part III, Chapter VII, the paraffins or the alcohols are made; but whereas the units which are joined together to make these are usually all alike, except at the two ends of the chain, the amino-acids which are strung together are usually of many different kinds, even in a single kind of protein.

If you could compare the organic compounds to necklaces of beads, then with the paraffins, for instance, all the beads would be of the same size, shape and colour, except that the two ends would have clasps on. But with the proteins the different beads would be of different sizes and shapes and colours.

Now when an animal eats a plant, or eats another animal, the digestive juices in its stomach and intestine split up the proteins of the plant or animal food into separate amino-acids. These get absorbed into the blood, and by it are taken to the different tissues of the body, where they are built up into proteins again; for just as out of a box with ten different kinds of beads you could make a great many quite different-looking necklaces by leaving out one or another kind of bead, or by arranging the same selection of beads in different ways, so a whole lot of different kinds of proteins can be made out of the quite small assortment of amino-acids that exist in food.

In fact, each kind of animal seems to have its own characteristic kinds of proteins; and this fact of having its own special proteins probably has more to do with its being different from all other kinds of animals than has anything else. So this power of an animal to digest proteins into amino-acids and build them again into new kinds of protein is one of the most important things about animal life.

So much for the building up of nitrogen compounds in living bodies : now for their breaking down. The waste nitrogen that has to be got rid of by animals leaves the body through the kidneys in the shape of simple organic compounds, of which urea (CON_2H_4) is the best known. Urea, by the way, is interesting for another reason: it was the first organic compound to be built up artificially in a chemical laboratory.

When a plant or an animal dies, decay sets in. And when parts of an animal or plant are shed, as happens with plants every year when they shed their leaves, or with birds when they moult their feathers, these too will decay. Decay, as we saw in "Simple Science," p. 27, is mainly due to various microscopic bacteria. They can only absorb simple substances, so to get these they must break down the proteins and other complicated substances in the tissue of the dead plant or animal. They only use a small amount for their own purposes; the rest escapes into the air as carbon dioxide, or into the soil in the form of various simple compounds. The usual form into which the nitrogen of tissues is turned by decay is an extremely simple one, namely ammonia. Everyone knows ammonia with its pungent smell and its use for cleaning things. It is a compound of nitrogen and hydrogen—NH_3. At least that is the formula for ammonia gas:

liquid ammonia is a combination of this with water, and has the formula NH_4OH. The urea and other compounds got rid of by animals are also turned into ammonia or ammonium salts by decay bacteria, as everyone knows who has smelt ammonia in a stable. So ammonia is the common end-point for the breaking down of all nitrogen compounds in life.

The next step in the circulation is an interesting one, quite different from anything found with carbon. There the end-product of decay and excretion was carbon dioxide, which is available at once to green plants as the starting point of a fresh building-up. But green plants cannot absorb ammonia ; before it can be used as a source of nitrogen, it has to be turned into nitrates in the soil. We shall explain in Chapter V how this is accomplished in a very strange way. It is done by other kinds of bacteria than those of decay. They make the ammonia combine with oxygen, forming nitric acid—HNO_3—which then reacts with other substances in the soil to produce nitrates. The combination of the oxygen with the ammonia is a form of the slow burning we talked of in "Simple Science," Part II, and therefore gives out energy. The bacteria which cause this change to happen use the energy for their own growth; but they are also of the greatest importance to us, for without them there would be a gap in the circulation, and plants could not get at the nitrogen and build it up into the form in which we must have it if we are to digest it.

But that is not the whole story. Not all the nitrogen from animal and plant bodies gets turned into nitrates. Some of the ammonia breaks down into water and nitrogen; the latter leaks back into the air in the form of nitrogen gas, and is therefore of no use to green plants.

This is chiefly due to still other kinds of bacteria which turn ammonia into nitrogen gas instead of into nitrates, but some nitrogen escapes in gas-form in the burning of wood, either accidentally in forest fires or deliberately by men, and also in the burning of coal, which contains on the average about 1 per cent. of nitrogen.

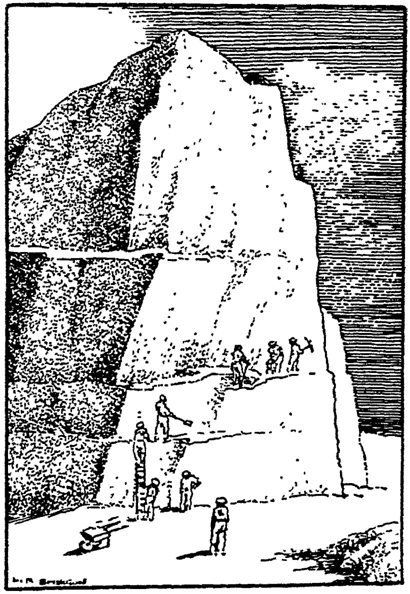


FIG. 68.—*Men digging guano on an island off the west coast of South America. The whole thickness of the cliff is guano, formed from the accumulation of sea-birds' droppings.*

Nitrogen can also be lost out of the life-circulation by being locked up. A small amount is locked up in coal, a fair amount in peat. There is a great deal locked up in guano, which consists of the masses of sea-birds' dung which accumulate, often in layers many yards thick, in dry climates where the dung is not washed away by rain. There is also a great deal locked up in the beds of saltpetre, which chemically consist either of sodium nitrate or of potassium nitrate. The biggest beds are in Chile in South America: they vary in thickness from a few inches up to twelve feet, and are found along the eastern slopes of the coast range of mountains for over 250 miles. It is not known from what source these beds

were formed, but in any case the nitrogen in them is temporarily locked out of the circulation.

The great difference between the carbon cycle and the nitrogen cycle is this, that whereas in both cases there is a huge reservoir of the element in gas form in the air and dissolved in water, the reservoir of nitrogen is of no use to green plants, whereas the reservoir of carbon dioxide is what they draw on for their supplies of carbon. The reservoir of nitrogen is enormous—three-quarters of the weight of the atmosphere is pure nitrogen—but it is as useless to green plants as an ocean of salt water is to a man dying of thirst.

As some nitrogen is all the time leaking out of the circulation into the air in the form of nitrogen gas, which cannot be used, it might be supposed that the supply of nitrogen available to plants, and so eventually to animals, would gradually be growing smaller and smaller until all living things died of nitrogen starvation. Luckily, however, there are certain ways in which it can be brought back into circulation. Again it is certain bacteria which are performing this service for the rest of life. Some kinds of bacteria can deal with nitrogen in gas form, and use it to make nitrogen compounds, which can in their turn be used by green plants. We say that they can *fix* atmospheric nitrogen. Some of these nitrogen-fixing bacteria live free in the soil; others, as we shall describe more fully in Chapter V, live on the roots of certain plants such as clovers and beans. Besides bacteria, it seems probable that certain mould-like fungi have the same power. These fungi generally grow on the roots of certain plants, and are called *mycorrhiza*, which means root-mould. They get most of their carbon from the green plants, and in return hand over some of the nitrogen which they have

built up into a form available for green plants. Thus the mycorrhiza and the plant on whose roots it grows form a sort of partnership, from which both sides reap an advantage.

By these means, enough nitrogen is brought back from the useless gas form to keep the circulation going.

However, in spite of this, most plants, whether living in water or on land, do not get as much nitrogen as they could make use of. They exist in a chronic state of slight nitrogen-hunger. This is because nitrates, the chemical form in which alone nitrogen is available to most plants, are relatively scarce in most soils and most waters. Hardly any cultivated lands exist where the addition of extra nitrates will not cause an increased crop: and the same is true of water for the growth of diatoms and other water plants. Sometimes, to get the good effect of the nitrates, other substances too must be added, such as phosphorus, which we shall discuss later. In such cases there is an even greater shortage of phosphorus than of nitrogen. But if this check to growth is removed, the addition of nitrogen will have an appreciable effect. Thus anything that can be done artificially to bring nitrogen gas out of the atmosphere into circulation, by converting it into a form available for plants, will increase the world's nitrogen income and make possible an increased yield of agricultural products from the land.

Two chief methods have been discovered for doing this: one electrical, the other chemical. The chemical one consists in making hydrogen combine with nitrogen to form ammonia. This reaction will not happen with pure hydrogen and nitrogen at ordinary temperature and pressure. However, with high temperatures (several hundred degrees centigrade) and high pressures (100 to 1,000

atmospheres in the various processes used), and with the help of a catalyst or "chemical encourager" ("Simple Science," p. 675), the gases will combine to make ammonia. The ammonia can then be easily used to make chemical fertilisers. A process of this kind was invented in Germany, and helped the Germans during the war to withstand the effects of the Allied blockade by making them independent of imported nitrates.

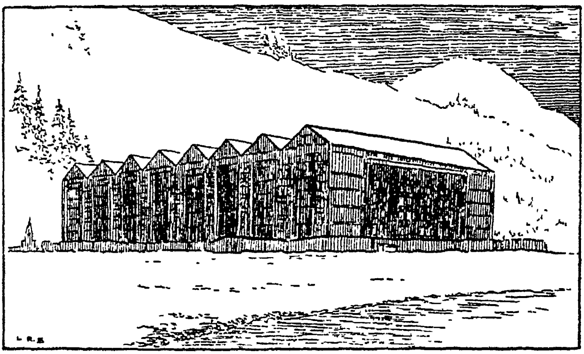


FIG. 69.—*Part of the big nitrate factory at Saaheim in Norway. It is in this building that the nitric peroxide formed from the air by the aid of the electric arc is absorbed by water to produce nitric acid.*

In the electrical method, nothing but air is used as raw material, and some of the nitrogen is made to combine with some of the oxygen to give nitric acid ("Simple Science," p. 606), by running the air through a sort of oven in which an electric arc is continuously generated. The temperature in the electric arc is about 3,000° C., and at this high temperature the oxygen and nitrogen combine, giving first nitric oxide gas (NO) and then nitric peroxide gas (NO_2). The nitric oxide is run up through towers in

which water is slowly streaming down, and there combines with the water to produce nitric acid (HNO_3). The nitric acid can then be used to make nitrates. This process can only be carried on economically in countries like Norway, where electricity is very cheap owing to abundant water-power.

So man has learnt to do artificially what the nitrogen-fixing bacteria (p. 140) do by nature—namely, to "fix" nitrogen gas in an available chemical form. However, for

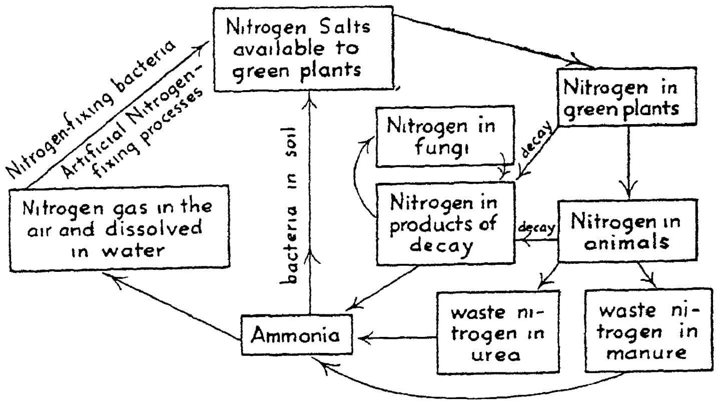


FIG. 70.—*The Nitrogen Cycle, omitting Nitrogen locked up in solid form.*

this he has to use enormous temperatures or pressures, while the bacteria do their work under everyday conditions. All the same, these discoveries are of great importance, since by this means we can, if we want to, increase the amount of nitrogen circulating through living creatures within very wide limits.

The essentials of the nitrogen cycle can be summarised in a diagram, as we did for the carbon cycle. It will be seen how different the two are.

The Phosphorus Cycle

Besides the circulation of carbon and nitrogen through living things, that of phosphorus is very important. Phosphorus, like nitrogen, is one of those elements of which there is often a shortage. In many places on the earth's surface the growth of plants would be greater if only there were more phosphorus available. We shall see in Chapter V that this is true of most cultivated soils. Adding fertilisers with phosphorus in them will almost always increase the yield of the crop.

The same thing is true of the sea. The chief vegetable crop which grows in the sea consists of the microscopic plants called diatoms, which are, of course, confined to the surface layers where light can penetrate. The number of diatoms in a given volume of sea-water can be counted. They are first caught in fine-meshed tow-nets and then counted in a special counting apparatus under a microscope. If they are counted at regular intervals throughout the year at any place in the temperate zone, it is found in the winter that there are very few. As the temperature of the water grows higher, the number steadily increases until about the end of May. From then on, however, their numbers gradually diminish instead of increasing still more, as might be expected since the temperature of the water, and therefore the chemical activity of the diatoms, is still going up. It has been found that this check to their multiplication is due to shortage of phosphorus in the surface layers. As long as there is enough phosphorus, rising temperature causes increased multiplication, but there is only enough phosphorus for a certain number of diatoms.

Much of the phosphorus which is used by the diatoms

gets carried away from the surface layers when the diatoms die and sink down into the deeper water. Here they decay, and the phosphorus comes back into the water in the shape of dissolved salts (phosphates).

As long as the temperature of the air is high, the surface layers of the sea are warmer and therefore lighter than the lower layers, and so will remain at the surface. But in the winter they will be cooled down to a lower temperature, which will make them heavier. Accordingly they will sink down, and some of the deeper water will come to the surface to take their place. By this means the phosphorus in the top layers is replenished, and a new crop of diatoms can grow next year until it again is exhausted. Phosphorus here each year acts as what we call a limiting factor. By this we mean that it is the amount of phosphorus, not the amount of nitrogen or carbon or oxygen, which sets the limit to the size of the diatom crop.

On land, the phosphorus taken out of the soil into the bodies of plants and from them into the bodies of animals finds its way back again into phosphates during the process of decay. Phosphates can be absorbed by the roots of plants; so it might be thought that the phosphorus circulation went round in a satisfactory way. However, some of the soluble phosphates get into running water and are carried out to sea; and once in the sea, they are for the most part lost to the land. A little may come back in the form of fish caught by animals and men, but this is only a tiny fraction of what is lost.

The stores of locked-up phosphorus available to us to fertilise our fields as their natural phosphorus becomes exhausted consist mainly of guano (p. 139), which contains a good deal of phosphorus; some deposits which contain huge amounts of the fossilised dung of extinct animals;

and others which are full of the bones and teeth of fish. However, these stores of phosphorus are not large, and there is no artificial method of tapping any natural reservoir of unused phosphorus as there is for nitrogen. Phosphorus is a rather rare element, making up only about $\frac{1}{700}$ part of the earth's crust, as opposed for instance to calcium, which constitutes about a thirtieth, and iron, which accounts for nearly a twentieth. Each adult man or woman contains about $1\frac{1}{2}$ lbs. of phosphorus: in the whole human population of the world there are about a million tons of this element.

The most serious avoidable waste comes from the common practice of disposing of human sewage into the sea. About 200,000 tons of phosphorus each year are lost in this way in the United States alone.

Thus with phosphorus, as with carbon used for fuel, man is largely drawing on capital which nature has accumulated during previous ages. However, while we can substitute other substances or processes for carbon in order to produce power, there is no substitute for phosphorus which will keep up the fertility of the soil. Unless we take steps to prevent the waste which goes on at present, the world will be suffering from a phosphorus shortage, and therefore a crop shortage, in quite a few generations.

The Wastefulness of Man

This wastefulness of man is very pronounced at the present period of history. He is, as we have seen, using up his capital—of "bottled sunlight" in the shape of coal, of other stored carbon like oil, of stored nitrates and phosphates—far faster than it was accumulated by nature. He is doing just the same sort of thing with regard to forests, wild animals, and even soil. Forests are cut down

to provide wood for fuel and paper-making ("Simple Science," Part II, Chapter VI), but mostly to clear the land for crops or grazing. Sometimes the face of a country is entirely changed by the destruction of forests. Over huge areas of China, for example, there is not a tree to be seen except a few ornamental ones in gardens. There is no firewood for fuel, and as there is no coal available for the common people, they have to burn refuse.

When forests are cut down, provision is rarely made for replanting on a proper scale. Some countries have taken steps about this. In the United States, big areas have been proclaimed forest reserves. In countries like Germany and Switzerland, many cities and parishes have their own forests which are kept up so as to yield a steady income. In this country the Forestry Commission is planting hundreds of thousands of trees on waste land. But unless similar steps are taken by all the main forest countries, there will be a world shortage of wood in a very few generations.

The cutting down of forests may also be very bad for the soil. Where hills or mountains are covered with trees, the water that falls as rain cannot run off quickly. The shade of the trees prevents it evaporating quickly and the soil holds it like a sponge, only allowing it to trickle down gradually. But if the forests are cut down, the soil is no longer protected by their foliage nor held together by their roots, and after a time is washed away. Then when rain falls, there is nothing to hold it back, and it all runs off quickly, eroding the surface still further, and pouring down to the lowlands in torrents. Even if exactly the same amount of rain as before falls on the hills they will now be dry and barren, because it runs away so quickly. And instead of the lowlands receiving

a steady supply of water in the streams and rivers from the hills, most of the water will come down in the form of dangerous floods, while the rest of the time there will be too little water.

The mountains along the coast of Illyria and Dalmatia are good examples of these disastrous effects of reckless

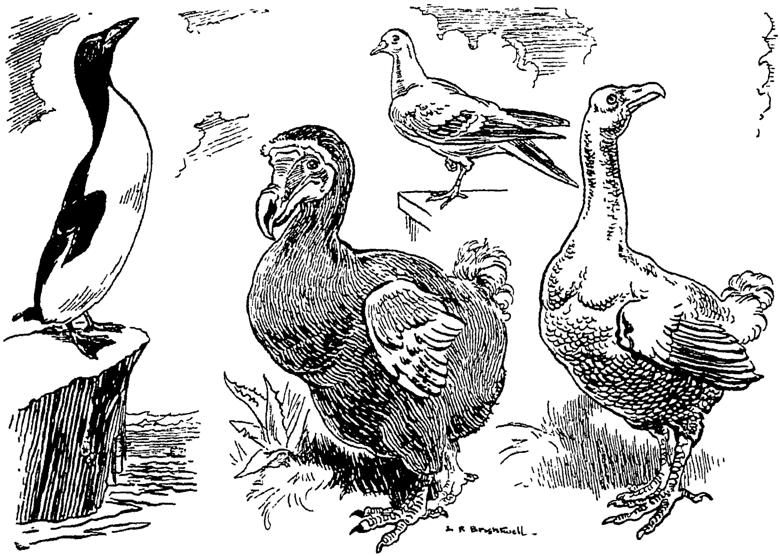


FIG. 71.—*Some birds which have become extinct in historic times. From left to right: Great Auk, Dodo, Passenger Pigeon, Solitaire.*

cutting of forests. In many parts of Africa, too, deforestation has had serious results. In some parts of Kenya and Tanganyika the soil has been almost entirely washed away, leaving only bare rock, and the occasional torrents from the rains make the streams cut deep bare gorges into the countryside instead of pleasant little valleys full

of vegetation. In all such cases replanting of trees in the right situation ought to be done at once. But even then it will take a very long time for the soil to form again.

Besides the actual loss of soil, man is often removing valuable elements out of soil by thoughtless cultivation or grazing. We have seen what is happening about phosphorus; we shall see in a later chapter that the same thing applies to other elements. Every product of the land—every quarter of wheat, every gallon of milk,

FIG. 72.—*In the nineteenth century vast numbers of Bison were slaughtered on the plains of North America.*

every pound of beef or mutton, every bale of wool—represents so much of nitrogen, calcium, iron, sulphur and other elements taken out of the capital store in the soil. Unless we put a corresponding amount back, in the shape of fertilisers or in other ways, we are living on capital: and this is a process that cannot go on for ever.

With many wild animals too the situation is serious. Some kinds of animals have actually been exterminated. This is a real crime, for they can never be restored to the world. The Great Auk was exterminated by sailors who

killed the birds for food. The big flightless pigeons called Dodo and Solitaire are now altogether extinct. So is the Passenger Pigeon in America, although less than a hundred years ago its flocks were so large as to darken the sky.

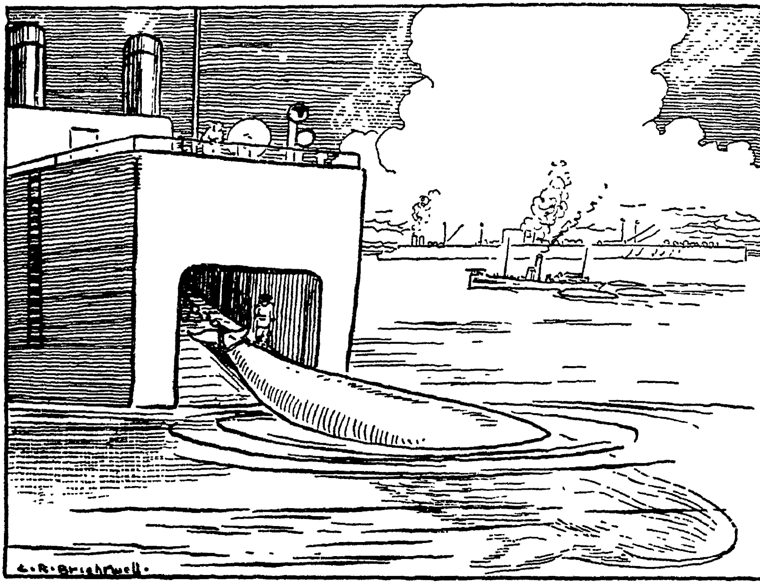


FIG. 73.—*How whales are being exterminated. A "factory ship" in the Antarctic. After the whales are harpooned, they are hauled aboard through a trap-door, in this case in the square stern, and their blubber converted into oil on the ship. In the background is another "factory ship" and a hunting ship towing whales inflated after being killed.*

Other animals have been brought to the verge of extinction. The huge Bison (often wrongly called Buffalo) used to roam the Great Plains of North America in herds of tens and even hundreds of thousands. They were shot down to provide meat and buffalo rugs (and also

in some cases to bring the Red Indians to submit to the white men by depriving them of their natural food-supply). To-day only a few small herds survive, jealously guarded in nature reserves. The European Bison is in an even more parlous condition.

Sometimes men are so greedy that they kill the goose which lays the golden eggs. In the seventeenth century there was a rich whaling industry off the coasts of Spitsbergen, but the whalers killed so many whales for the sake of their oil that the industry died out. To-day there is very little whaling anywhere in the Northern hemisphere because the whales there have been so persecuted. For whaling, people now go chiefly to the Antarctic; but there a similar situation is developing, and the whales are now being killed off much faster than they are reproducing themselves.

The same thing threatened the fur seal industry during last century; the position became so serious that finally an International Agreement was drawn up to protect the seals at their breeding places. This was so successful that the fur seals are now quite abundant again. Something of the sort will have to be done with whales if there is to be any whaling industry in our grandchildren's time.

In this country many beautiful and interesting kinds of birds are now almost or quite extinct. Kites used to act as scavengers in the streets of London as late as the seventeenth century. Now there are only two or three pairs in Britain. The splendid Great Bustard used to nest in East Anglia: now there are none. The Avocet and the Ruff were common shore-birds in this country not many generations back: they still breed in Holland, but have been killed out here.

One of the first things made possible by the application of science was the rapid exploitation of the riches of the earth in new ways and on a larger scale. We are now coming to see that there is a right way and a wrong way of doing this. Further scientific study is revealing

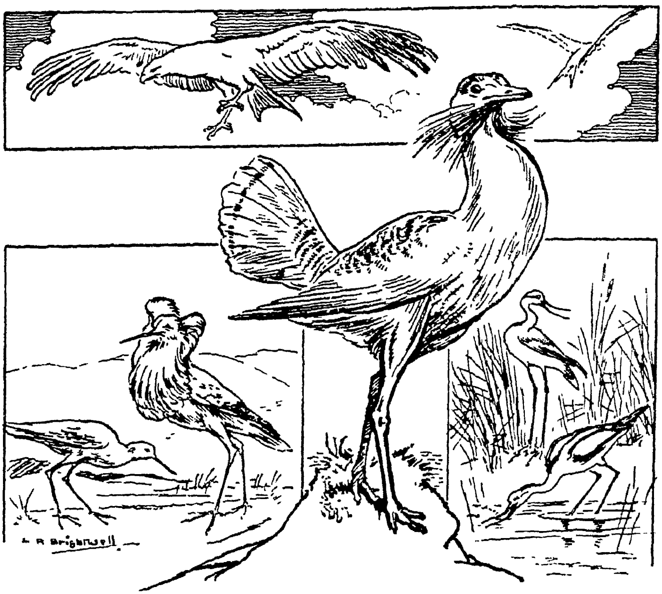


FIG. 74.—*Some birds which used to breed in Britain, but now have been almost or quite exterminated as breeding species. Above, Kite; left, Ruff; centre, Great Bustard; right, Avocet.*

the extent of the stored capital available and the amount of income that we can take without drawing seriously on the capital or dangerously depleting the reserves. It is showing us the difference between recklessness and waste on the one side, prudent utilisation and good

husbandry on the other. It is discovering methods of replenishing depleted capital stocks. In exploiting natural resources the human race has to run its business relations with the world at large on proper lines, just as much as an individual shopkeeper has to run his trading relations on proper business lines with his customers and the dealers who supply him with goods. Finding out scientific facts and rules about natural resources can help us to do this in the right way.

CHAPTER IV

SOIL

How Soil is Formed—How Soil holds Water—The Structure of Soil—Harrowing and Rolling—Early and Late Soils—The Effects of Lime; Ploughing—Plant-remains in Soil

How Soil is Formed

In the previous chapter we explained a good deal about the rocks of the earth's crust. But we said nothing about one layer of the crust which, though extremely thin in comparison with the rock layers, is very important to us. This thin but important layer is the layer at the surface. It is the layer of soil. It is so important because it is the soil which supports plant growth on land. The gardener gets his flowers and vegetables out of the soil: the farmer must have good soil if he is to supply us with food.

Let us think about some of the things that farmers do to the soil. They plough it; they roll it; they harrow it. Sometimes they leave it uncropped or fallow for a whole season; sometimes they add lime to it, or mineral fertilisers, or farmyard manure. Ditching and draining have to be done now and again. Do you know why they do these different things? Farmers call some soils heavy and others light; some warm and others cold; some rich and others poor. Some soils are called sour, and certain garden soils are said to be sick. Do you know what these words really mean when applied to soil? Then you will often notice if you are in the country that in one and the same neighbourhood some lands are cultivated for crops, others are laid down to grass, others left as rough pasture or wild moorland, others again kept under timber. Is there any reason for this difference? And if so, what is it?

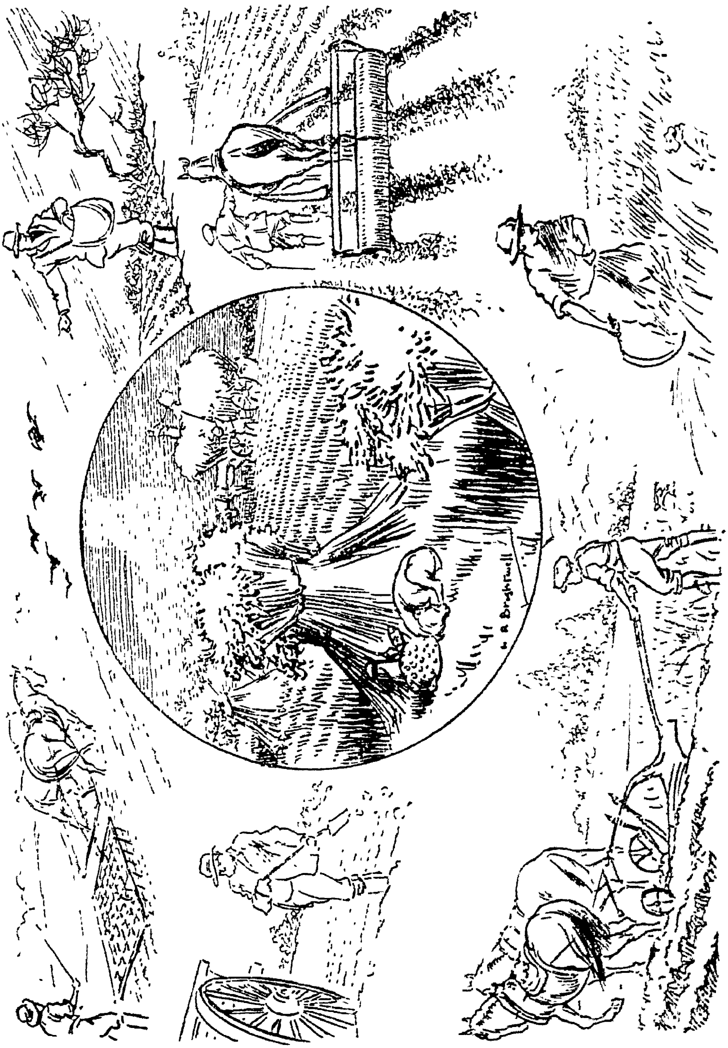


FIG. 75.—*What the farmer does on the land. Ploughing, spreading lime, harrowing, sowing, rolling, reaping. Centre: the harvest.*

These are some of the questions to which we would like to find an answer. The farmer might say he does what he does at different times of the year because he finds it is good for the crops, and grows what he grows in different places because he finds it pays.

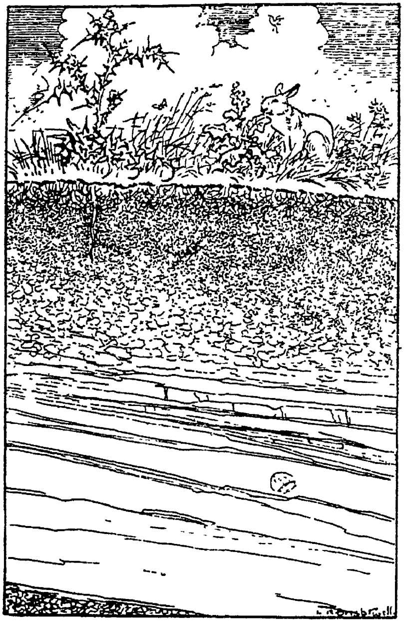


FIG. 76.—*The top of a quarry. Plants grow in the soil, the soil passes into the subsoil, and the subsoil passes into rock.*

That is a perfectly good answer. But it is not a scientific answer. In science we want to know *why* and *how*: what is more, we believe that if we find out why something happens, how it works, we will in the long run be able to improve the process and get better results, even if practical men have been getting quite good results for centuries without understanding the scientific reasons for what they were doing.

In order to get a scientific answer to questions of this sort, we must go back to the soil and find out what we can about it.

What exactly *is* soil? We all know it is the earth in which plants grow. Bare rock will not support plants. Even when you see tiny plants managing to grow on a rock, their roots go down into cracks where there is a little soil. But what *exactly* is soil? And how is it formed? And why can plants grow in it and not elsewhere in nature?

Let us first see if we can find out how soil is formed. We can begin to get an answer to this question by going to a quarry or a cutting where a set of rock-layers is exposed. At the bottom will be some sort of rock—it may be sandstone or granite or limestone or basalt or chalk. At the top is a layer of soil, more or less dark in colour, with plants growing in it. Between the rock and the soil is usually another layer, which is generally called the subsoil because it is found under the soil. At the bottom it grades into the rock-layer, at the top into the soil. Sometimes it is very thin, and sometimes you cannot distinguish it from the soil just by looking at it.

When there is a well-marked subsoil layer, the usual difference between its upper part and the soil is that the subsoil is not dark-coloured like the soil; and it is often harder to dig than the soil. The chief difference between the rock and the bottom of the subsoil is that the rock is solid, then come obvious rock fragments, and then the finely divided material of the subsoil. This looks as if the soil was made by the breaking up and altering of rock where it comes to the surface. This is actually what happens. The rock surface is gradually broken up, partly by water getting into tiny cracks and freezing, partly by the expansion and contraction caused by changes in temperature, and sometimes by acid dissolved in water. This is called weathering.

If you can find an inland cliff in your neighbourhood, it will have a mass of stones lying piled against the foot of it. This has obviously come from the face of the cliff, by bits being split off and falling down, for you will find the stones are of the same kind of rock as the cliff. (Bits also fall off seaside cliffs in the same way; but here they are generally broken up and swept away by the waves so that a big sloping pile does not accumulate.) If you look at

the pile carefully, you will see some bits of rock just like those in the face of the cliff, and others with crumbly surfaces. You will also find little patches of soil among

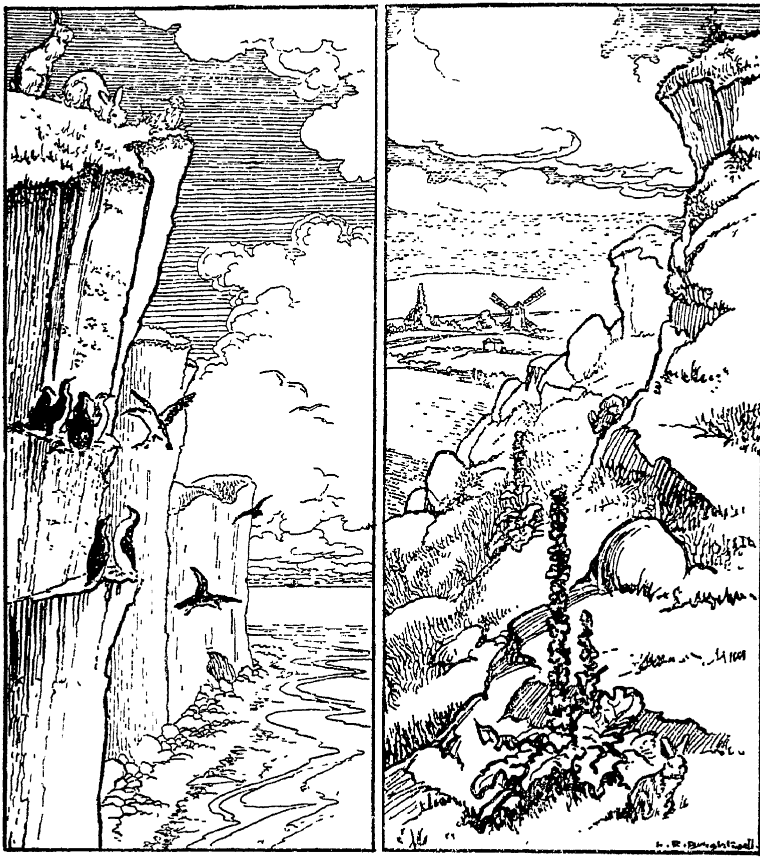


FIG. 77.—*A sea-cliff and an inland cliff. The sea-cliff is sheer because the waves wash away the bits that fall down; under the inland cliff they accumulate to make a slope, and weather to form soil.*

the stones. This soil must have been produced from the heap—no one would have carried it there, and there is more than could have fallen down from the top. It is clear that it must have come from the particles crumbled off from the surfaces of the bits of rock. It has been produced here

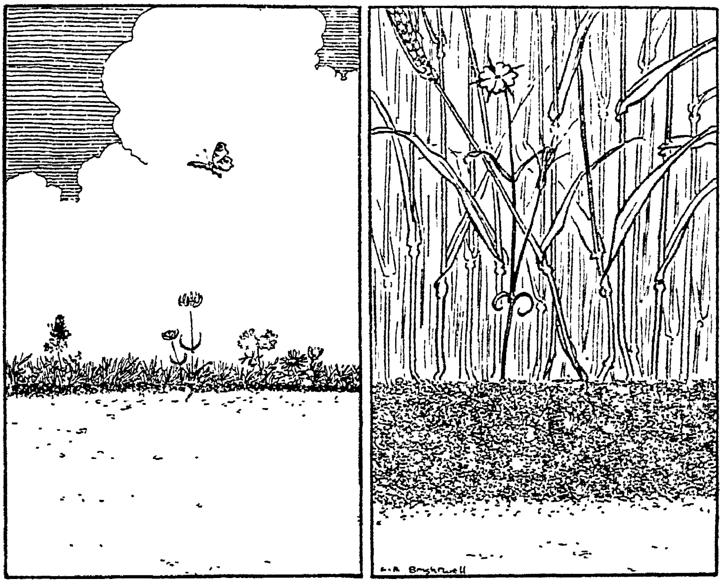


FIG. 78.—*Left, a trench cut in a chalk down shows how thin is the layer of soil above the chalk rock. Right, a field in the same neighbourhood: continued cultivation has produced a much thicker layer of soil.*

by weathering. It does not come from the top of the cliff when the stones break off: if you can find a fresh rock-fall, you will see there is no soil among the stones there.

The same kind of thing happens with more or less flat surfaces of rock, only here bits of rock cannot break off and fall down, so the rock weathers away where it lies.

Sometimes the solid rock will come quite close to the sur face, the layers of soil will be quite thin, and there will b hardly any subsoil different from the rock. This happen on chalk downs, for instance. In other cases there will b a gradual passage of rock into soil through a thick laye that is neither rock nor soil.

So we see that one way for soil to be formed is by th weathering of the top of a rock-layer that is exposed at th surface of the earth. However, not all soil is formed i this way. Sometimes particles of ground-up rock, or c soil already formed, are carried down by water, or blow away by wind, or transported by ice, as we explained i Chapter II (pp. 76, 102), and then deposited far from the original home. By these means alluvial deposits (p. 75) ar built up in the broad flood-plains of rivers, and sheets c boulder clay (p. 76) are spread over parts of the countr which once were under ice. In some regions of the worl which have a dry climate, like parts of the Chinese empir wind-blown particles may accumulate to build up thic layers of what is called loess.

Materials like these are not solid rock: they are mad of fine particles which are already broken up. If they ar made of properly weathered rock-material, and if they ar laid down in the right sort of surface layer, they forı ready-made soil: for instance, the material deposited b the Nile each year when it floods its banks. But not a such materials are soil. If you look at a quarry or trenc in an alluvial plain or in a part of England covered wit boulder-clay, you will again see a dark layer of real sc more or less sharply marked off from the subsoil belov So there are two steps in the formation of soil from roc One is the breaking up of the rock into a mass of loo particles; the other is the turning of the top layer of the

loose particles into the actual dark soil. Sometimes both processes go on in one place: we call soils formed in this way sedentary soils. Sometimes the splitting up goes on in one place and the particles are then moved to some other place where true soil is formed: such soils we call transported soils.

You should try to see the process of soil-formation in as many places as possible, by looking at cliffs and quarries, river banks and cuttings, and by digging trenches or holes in gardens and fields of various kinds. You should make notes of the thickness and colour of the soil, the kinds of plants that grow in it, the sort of subsoil, whether it grades down into rock, how easy to dig the soil is, whether the subsoil is much more difficult to dig, and how far down the roots of the plants go. You should also try to find out with the help of a geological map the names and kinds of the rocks and drift deposits below the soils. One thing you should certainly try to do is to compare the soil formed from one and the same kind of rock or subsoil in different conditions; for instance, in a wood, a pasture, and a ploughed field. The difference is sometimes very striking, as on the chalk downs, where the soil is very thin under the open turf but much thicker in the cultivated fields.

One important thing which you will find out if you look at enough samples of soil is that there are many different kinds of soil. The most obvious difference is in the texture of the soil, whether it is loose and easy to dig, or firm and hard to dig—as gardeners and farmers say, whether it is light or heavy. You will soon see that this difference has largely to do with the size of the particles of which the soil is made. The light soils are made of bigger particles, the heavy soils of smaller particles. In fact, the light soils are mainly sand, the heavy soils mainly

clay. In between the sandy soils and the clay soils you will find other soils which are moderately easy to dig, and made of a mixture of large and small particles, with intermediate-sized ones as well. These are what the farmer calls loams. Of course, there are no hard-and-fast lines between the different kinds. There are very coarse sands

FIG. 79.—*Digging and stacking peat on a moor.*

and finer sands, light or sandy loams and heavy or clayey loams, and clays of different degrees of heaviness.

Then there is another main kind of soil, which differs from ordinary sands or loams or clays in having a mass of plant remains in it. In its purest form, this is what we call peat. Peat contains so much plant material and so little rock material that it can be burnt. In some parts of the country, especially where there are big moors, as in

parts of Ireland and Scotland, oblong turves are cut out of the peat-bogs and dried in stacks, and are the chief fuel of the peasants. Here again there are gradations from peat that can be used as fuel to peaty sand which has a good many plant remains in it, but too much rock material to burn.

It is interesting to collect samples of as many different kinds of soil as you can find. If you cannot get what you want yourself, you can probably arrange with one of the County Agricultural Organisers to send samples.

How Soil holds Water

The next thing to do is to find out something more as to what else is in soil besides solid rock-particles or plant remains. The most obvious thing is water. If you dig up a sample of soil and weigh it, and then weigh it again after you have allowed it to dry under cover in a hot place, you will find it has lost weight. This difference in weight represents the amount of water lost by evaporation. But if you now take the same sample of soil and heat it in an oven (105° to 110° C. is the best temperature) and then weigh it again, you will find that there has been a further loss of weight. It must be cooled in dried air before weighing, since if the air contains water vapour the oven-dried soil will take up moisture from it. The soil was able to hold on to a certain amount of water at ordinary temperatures: it needed the high temperature of the oven to drive all the water out.

Another thing you can easily find out is that different soils have different capacities for holding on to water in this way. An air-dried sample of clay will contain much more water than one of sand, and so will lose much more weight when heated in an oven. If you put a square slab of clay on a board and dry it after marking its outline, you

will find that drying makes it shrink considerably (Fig. 80) this is due to its losing water.

How does the soil hold water? Before we answer this let us consider one or two experiments. If we take a fin

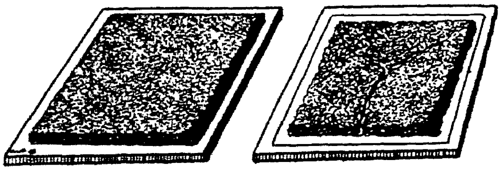


FIG. 80.—*Left, a piece of damp clay is spread on a board and a line draw round its edge. Right, after drying; the clay has shrunk considerab as well as cracking.*

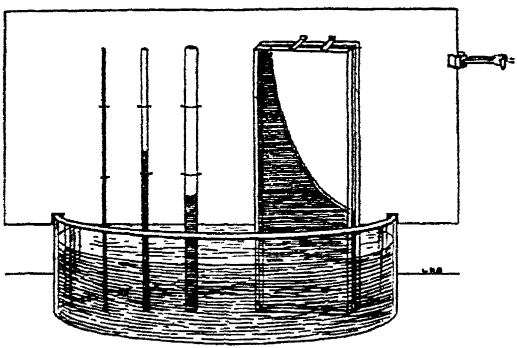


FIG. 81.—*The capillary effect: water rises in narrow spaces. Left, rises highest in the narrowest tube. Right, when two plates of glass a fixed at a small angle, the water rises highest where the plates are close*

glass tube, such as can easily be drawn down from a piec of ordinary glass tube heated in a flame, and fix it uprigl so that the lower part of it dips into water, it will be foun that the surface of the water in the tube stands higher tha the outside level. It is best to push the tube well down in

the water and then to lift it up somewhat before fixing it, to make sure that it is wet inside. The finer the tube the higher the water will stand in it: if the inside of the tube is only about $\frac{1}{100}$th inch across, then the level in the tube will be about $2\frac{1}{4}$ inches above the surface of the water outside, but if the bore of the tube is $\frac{1}{25}$th inch across, the rise will only be just over $\frac{1}{2}$ inch. This rise of the water in narrow tubes is said to be due to capillary attraction: the word "capillary" comes from the Latin *capillus*, which means a hair, because it is very marked when the inside of the tube is as fine as a hair. The capillary effect will takeplace not only in tubes but in any very fine channel or crevice. For instance, if two pieces of glass are fastened so as to make a very small angle, and stood upright in water, the liquid will rise considerably in the angle, where the surfaces are exceedingly close together, and less and less as we go away from the angle, making the pretty curve shown in Fig. 81. The water can be coloured with a little red ink to make it show better, if wished.

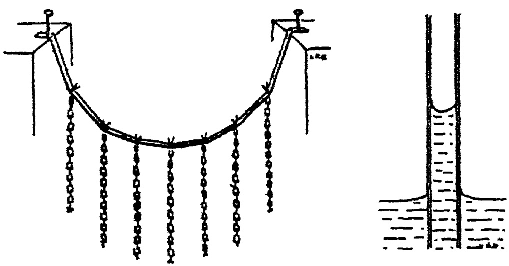


FIG. 82.—*Right, water in a narrow tube has a cup-shaped surface skin. This supports the column of water below, somewhat as an elastic band (left) will support a series of little chains.*

The water inside the narrow tube is not flat at the top, but takes up a cupped shape, higher at the outside than at the middle. The rise is connected with this peculiar behaviour. We saw in "Simple Science" (p. 18) that the surface of water behaves as an elastic skin, a fact which the man

of science describes by saying that water possesses "surface tension." A surface of the shape shown in Fig. 82 (right), fastened at the sides of the wall, will therefore exert an upward pull, and can hold up a column of water; very much as a flat elastic band, fastened at both ends, can hold up a series of little chains (Fig. 82, left).

A good illustration of capillary attraction acting in little irregular channels is given if we put a damp duster or damp wool hanging over the edge of a vessel of water, half in the water and half outside. The water will rise up in the stuff and run down the other side, until the whole vessel is empty (see Fig. 83). Again, if a tube full of fine dry sand is stood upright in a basin of water the water will rise in the crevices of the sand.

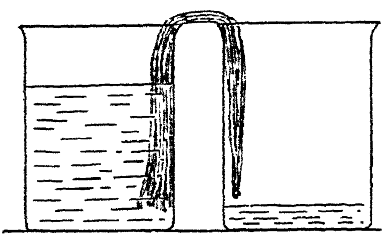


FIG. 83.—*If a piece of damp wool is hung over the edge of a beaker full of water into an empty beaker, water will rise in it by capillary attraction and then run down the other side until it is at the same level in both vessels.*

We can now understand that capillary attraction is very important for the question of water in the soil. In ordinary soils the water will run up into all the crevices between the particles and be held there firmly: it will not sink down rapidly, as it will in coarse sand or fine gravel, because, in garden soil, for instance, the crevices are so fine that the capillary effect is strong.

The particles of which a soil is made are of very different size in different kinds of soils. With the naked eye you can easily see the separate grains of which a coarse sand is made, while you cannot do this with a clay. If you take some sand and some finely powdered dry clay and make

each up with some water, the big sand particles will settle down almost at once, while the clayey water stays cloudy for hours or even days. The clay particles are so small that they have a very large surface in proportion to their mass, and settle extremely slowly (see p. 172, and "Simple Science," p. 405). To make sure that this will happen, you should use, instead of pure water, a weak (0·05 per cent.) solution of sodium carbonate. Without this, the tiny particles of the clay generally join up to make bigger particles, which, of course, sink more quickly. If you take samples of most ordinary soils you will find that they contain both sandy particles and clayey particles.

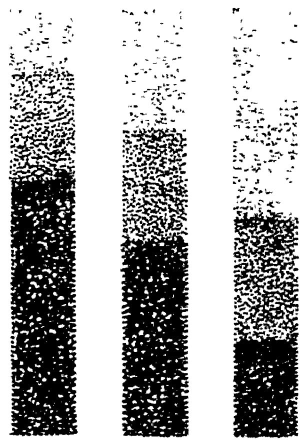


Fig. 84.—*The proportions of clay (fine dots), fine sand (medium dots), and coarse sand and grit (coarse, dark dots) in a sandy soil (left), a light loam (centre), and a heavy loam (right).*

Shake up samples of ordinary garden soil with water in a narrow cylinder and watch it settling. You will see that the coarse grit and sand fall first. The fine particles that make the water cloudy take a long time to settle; when they do eventually settle, you will find that they have made a layer of clay. If you do this with different kinds of soils such as sandy loams and heavy clays (of course using the same amounts of soil and water and the same sized cylinders in each case), you will find that the proportions of grit, sand, and clay are different in the different soils, and with the aid of a hand-lens and a ruler you can roughly measure the amounts.

A more accurate method is to shake up some soil with water and let it settle for a minute or two and then pour off the cloudy water into a big jar; then add more water to the coarse sediment at the bottom, shake up again, and go on doing this, pouring off the water each time into the same jar, until shaking up with the grit leaves the water no longer cloudy but practically clear. Then you will find that the sediment which would not float is made of large particles —grit and sand. Meanwhile, if you let the big jar stand for some time until it becomes clear, and then carefully pour or siphon out the water, you will find that the sediment here is sticky and fine-grained clay: in fact, it is practically the same as what you would get if you simply shook up finely divided modelling clay with water and let it settle. The proportions of sand and clay in different soils are different. It is interesting to take a number of clays and sands and loams and find out the proportions in each.

We can show that the size of the particles in a soil has a great deal to do with the way the soil behaves about water. Arrange equal amounts of sandy and dried clayey soil in glass cylinders (inverted lamp chimneys, for instance, with linen tied over their lower ends), and then pour water on them. The water will pass through the sand much more quickly. You will also find that less water stays in the sand and more in the clay. (It is best to pour the water through two or three times to make sure that the clay is thoroughly wetted, and then leave the soils until no more water drips from them. It is also best to make a few preliminary trials to get the soils packed just right: too loose or too tight packing will upset the results.) If you then rest the cylinders on quite dry sand, you will find that this gets wet: water that was held fast by the wet soils when by themselves, is drawn out in some way by the dry sand

The soils, we may say, are now fully drained. The sand under the wet clay does not get so damp as under the wet sand: this must mean that the clay resists giving up

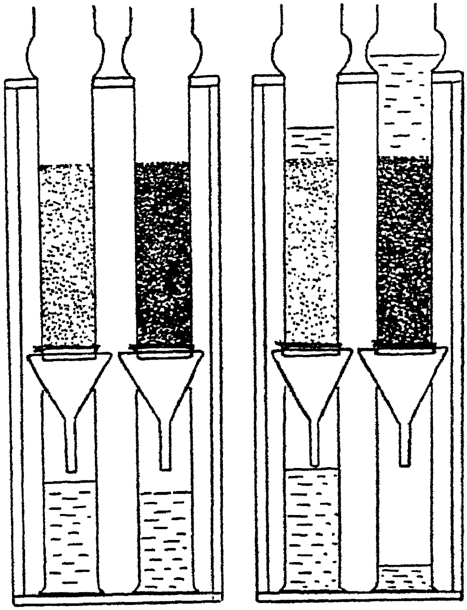


FIG. 85.—*Left, showing that a dry clay soil retains more water than a dry sandy soil. The clay is shown darker. Equal amounts of water were poured on to the two soils: more has come through the sandy soil. Right, wet clay soil allows much less water to pass through it than does wet sandy soil. Equal amounts of water were poured on the two soils after they had been saturated. After an hour, three-quarters of the water had passed through the sandy soil, but only a tenth through the clay soil.*

water more tenaciously than the sand. You can check this further by weighing the drained soils before and after drying, and so determining the amount of water in

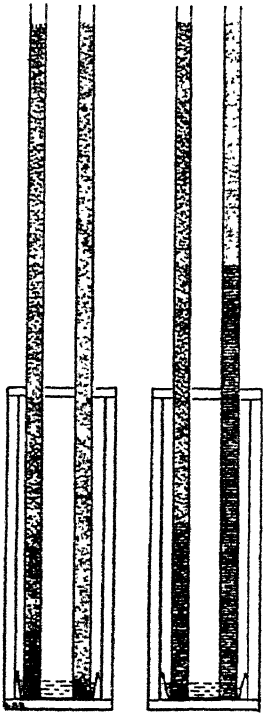


FIG. 86.—*Water rises more quickly in sand, but further in the long run in clay. Two tubes filled with dry sand (coarse dots) and dry powdered clay (fine dots) were stood with their lower ends in a vessel of water. Left, after half an hour the water has risen further in the sand. Right, after a month, it has risen further in the clay.*

them. The drained clay will contain much more water—perhaps twice as much or more—than the drained sand.

Then you can stand an ordinary plant-pot filled with moderately dry soil in a saucer of water. After some time, the soil becomes quite wet. This shows that water can rise in soil. By taking long tubes of different kinds of dry soil material—coarse sand, fine sand, powdered loam and clay—and standing them in water and seeing how fast and how far the water rises in them, you will find that the water starts to rise quickest in the coarse sand, slowest in the clay, but that it goes on rising longest in the clay so that it eventually stands higher there. The finer the particles of a soil, the slower water will rise in it, but the higher it can be raised. Here, too, you must be sure to get the right degree of packing in the soil. Just as wet clay shrinks more when dried than wet sand, so dry clay expands more than dry sand when it is wetted (Fig. 87).

Then you can try what happens when you puddle clay—that is to say, wet it and squeeze it tight. If you put puddled clay soil in

one funnel, and in another funnel some of the same soil to which nothing has been done, you will find that water will pass slowly through the untreated soil, but not at all through the puddled soil. In the same way, a layer of well-puddled clay will prevent water from rising in a tube full of dry soil. The water can be raised up to the layer of clay, but the soil above this layer will stay dry. On the other hand, sand cannot be puddled. You can squeeze pure sand together as much as you like, and it will still let water through.

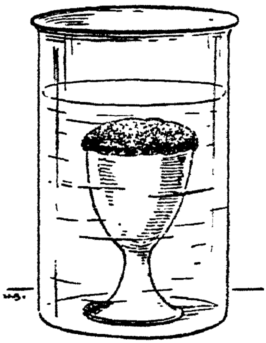


FIG. 87.—*Dry clay swells when wetted. An egg-cup filled level with the top with dry clay is put in water; the clay swells up and begins to spill over the rim.*

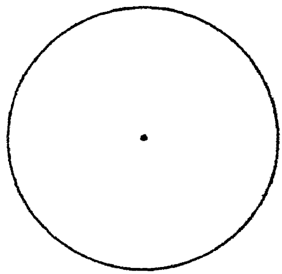


FIG. 88.—*The large circle and the dot represent the average sizes of a sand particle and a clay particle, much magnified. The sand particle is about $\frac{1}{100}$th of an inch across.*

The Structure of Soil

The reason for this is the different size of the particles in sand and clay. The particles in sand are very much larger, as you can measure for yourself under a microscope.

Even when they are squeezed together there will be spaces between them, and the water will trickle down, or percolate as it is called, through these. There will still be spaces between the particles of the squeezed clay. But these will be a great deal smaller than those in the sand, just as the spaces in a pile of peas would be much smaller than those in a pile of tennis balls. However, there is a further reason for the clay not letting water through. You will remember that wet soil, even when allowed to drain into dry sand, stuck to some of its water, and that clay was able to keep more than sand. This is due to the fact that when the water is reduced to a thin film over the soil particles it sticks much tighter to them. This again is owing to capillary attraction or surface tension. The film of water is like an elastic skin which clings to the grains of sand or particles of clay. Now clearly there will be much more of this water-film in the clay. For the film is on the surface of the particles, and a given bulk of small particles will have a much greater surface than the same bulk of large particles, as a little calculation will show. If mice were a little smaller than they are, or elephants a little bigger, it would take a million mice to weigh as much as one elephant. If so, then the million mice would have a hundred times as much surface as the elephant, even though their weight was the same as his. There will often be as much difference as there is between a mouse and an elephant in the size of the particles of fine and coarse soils, and therefore as much difference in the surface of the particles in a given bulk of soil, and therefore in the amount of water-film on the particles (Fig. 88).

When you wet and squeeze clay to puddle it, you squash the particles together until any tiny air-spaces there

may have been between them are got rid of, and the film of water on one particle comes to touch that on its neighbours. As there are no big spaces left anywhere in the mass for water to get away from the surface of the little clay particles, and as, when a film of water is spread on the surface of the particles, it acts like an elastic skin and sticks very tight to the solid surface, this means that it is almost impossible for water to pass through the puddled clay. The spaces are all filled with this tight-clinging film.

Puddled clay, however, would be useless as soil: plants would not grow in it. A good soil must have air in it as well as water, for plants need oxygen to breathe as much as animals do, and this is just as necessary for their roots as for their leaves or flowers. You can understand better the way in which air, water, and solid particles are arranged to form soil if you make a magnified model. Take a number of small marbles (or steel balls from ball-bearings). These represent the soil particles. Put them in a glass vessel which you can empty from the bottom in some way (you can easily make something of the sort with the aid of a broad glass tube, a cork pierced with a narrow glass tube, a bit of rubber tubing and a pinchcock). Then fill the vessel with some rather thick oil to represent the water in the soil. You can fill all the spaces between the marbles with oil: that would represent a soil that is waterlogged, with no air in it, and no good for plant growth. Then open the cock. You will find that a great deal of the oil will run out, but some will stay behind as a film on the surface of the marbles: the holding power of the surface film is greater than the downward pull of gravity. What you have now got represents the conditions in good soil. There is a mass of solid particles

which touch each other at a few points (with spherical objects like marbles, when packed as tightly as possible as in a pile of shot, each particle touches twelve others). Between the particles there is a continuous sheet of liquid in the shape of a thin film. There is also a system of air-spaces, and each little air-space communicates with its neighbours, so that the expanse of air is continuous. In actual soil the particles are not so regular in shape or size, so that sometimes an air-space may be cut off from its neighbours or filled up with water; but in general the arrangement is much the same. Soil thus has a very curious arrangement. It is made of solid, liquid, and gas —the soil particles, the water-film, and the air. And each of these, at least in moderately moist soil, makes a continuous structure. The solid soil particles touch their neighbours, the liquid water makes a continuous film, the gas-spaces communicate to make a continuous air network. So soil can have a certain rigidity like a solid, it can dissolve substances and move them from place to place like a liquid, and it can allow diffusion like a gas.

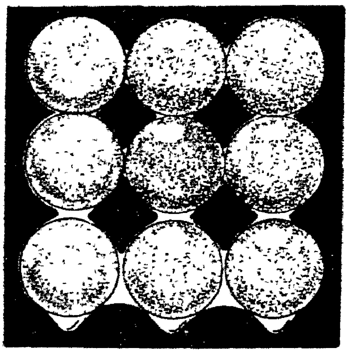


FIG. 89.—*Diagram of a model of a number of small balls which have been immersed in oil, and then allowed to drain. The oil makes a continuous film round the balls, with air-spaces between.*

Your model will also help you to understand a little more about the water in soils. The experiment we made before (p. 170) was simply to wet dried soils from underneath. The water rose by capillary attraction and water-

logged the soils, filling up all the spaces between the particles. But good soils, as we have just seen, are not water-logged, and the water is reduced to a film which on one side is in contact with solid particles, on the other with air-spaces.

The air-spaces in soil consist of a great number of little chambers communicating with each other by narrow channels. You can if you like see the shape of the air-space by using a model made of marbles as we have just described. Pack two layers of marbles into a tin box, pour in melted wax, and then carefully cut the marbles out. The wax that is left will give you the shape of the air-spaces between the marbles, and this will be quite like the conditions in soil, except that the air-spaces there are very much smaller, and also vary a good deal in shape and size from the regular arrangement in the model.

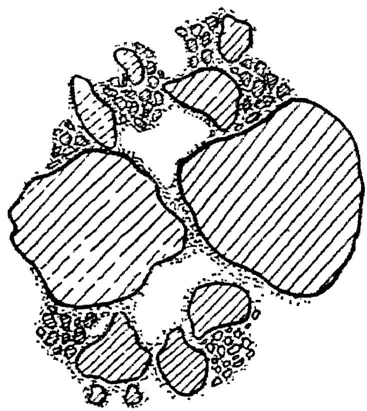


FIG. 90.—*Diagram of the structure of soil, much magnified. The solid particles (shaded) are grouped into "compound particles" (p. 190), surrounded with a water-film (dotted), and separated by air-spaces (white).*

The soil particles of course touch each other at a number of points. When there is only a little water in the soil, this will all be gathered round the points of contact between the solid particles to make thin rings of water. If the soil is made a little wetter, these rings will grow until they touch and join, so producing a continuous film of water lining all

the air-spaces, but still leaving a continuous network of air. Then if the soil is wetted still more, the water-films will join up in some of the narrow necks between the little air-spaces, so that some of these get shut off from their neighbours by water. And finally, of course, if you go on adding water you will eventually drive out all the air, and the soil will be water-logged.

Harrowing and Rolling

Now think of some wet soil, and of what must be happening to it on a dry day. Its top layers will lose some of their water by evaporation to the air. So long as there is a continuous film of water round the soil particles, some of the water in the lower layers will be pulled up by capillary attraction to take the place of what has been evaporated. But this is a slow process, and does not work over long distances. About 3 or 4 feet is the greatest depth to which water can be drawn up from deeper layers to the surface.

Once the film is broken, and the water is left in the shape of a number of separate rings round the points of contact between soil particles, movement of this sort is of course impossible: the water stays where it is. If the air is dry, some of the water will evaporate and slowly diffuse out into the air, so that the soil will get drier and drier. Meanwhile, however, the water in the water-rings cannot drain away, as it is held in place by surface tension, which is stronger than gravity for small films of water like this. Consequently the soil will stay slightly moist for a long time. This is one reason why it is important to have soil well cultivated and broken up into small particles. In this state there will be many more places where the tiny water-rings can form, and so it will hold moisture better.

In any case, however, it is a good thing to take pre-

cautions against the top layers of the soil drying out. One way of doing this is to make a layer of very dry soil at the top in which there is no continuous water-film. This will then act as a blanket against water-loss from below, for capillary action will be stopped, and the diffusion of water-vapour through such a layer is very slow. We can easily

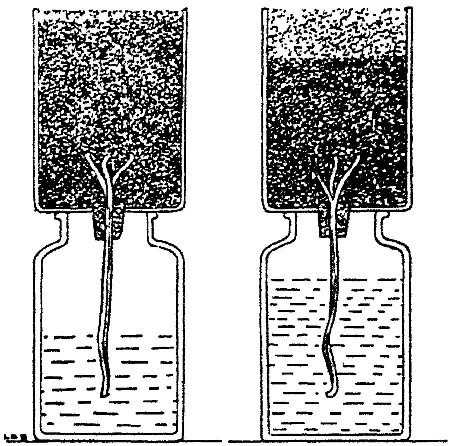


FIG. 91.—*Loose soil prevents evaporation. Two jars of water were arranged with lamp-wicks leading up into firm soil. In spite of evaporation from the upper surface, the soil was kept moist by the water rising by capillary attraction through the lamp-wicks. Then the top layer of soil in one pot (right) was stirred to make it loose. After one day's exposure to sun and wind, much less water had been evaporated from this pot than from the other.*

make an experiment to show the effect of such a blanket of dry soil. Take two jars or pots with a hole in the bottom: fill each of them firmly with soil, meanwhile arranging a lamp-wick, as shown in the picture, so as to spread out in the soil and to pass through a cork down

into another vessel below, three-parts full of water. Then wet the soil. Leave the soil untouched in one of the jars, but break up the top inch or so of the soil in the other jar by stirring it round carefully with a knife or other small tool, and repeat this miniature hoeing every day: this stirred layer of soil soon becomes much drier than the rest. You will find that the level of the water in the vessel below this jar sinks very much less than in that under the jar of untouched soil. This is because there is much less evaporation from the soil whose top layer has been stirred: the lamp-wick supplies water from below by capillary attraction to make up for what is lost above by evaporation.

Such a blanketing layer of material between moist soil and air is called a mulch. It need not be of soil: gardeners often make a mulch of straw or dead grass. But the usual method of mulching is to make a layer of dry soil by hoeing or harrowing. Another reason for mulching is to prevent the chilling of damp soil by evaporation.

Thus we see that one of the reasons for the farmer's harrowing his land after sowing is to keep as much moisture as possible in the soil. However, this effect is not quite so important as used to be believed. We now know that the water-film in moderately moist soil soon gets broken up into separate water-rings, and then there can be no raising of water from below by capillary attraction. It takes much longer for the deeper layers of the soil to lose their moisture than used to be supposed. Harrowing and other forms of mulching are useful to a certain extent and in certain circumstances in preventing soils from drying too quickly, but their main use is to get rid of weeds which would take from the soil a great deal of the water and plant-food that otherwise would go into

the crop; a further advantage is that they prevent the top layers from drying out to form a hard crust.

Rolling is another regular farming operation. It was once supposed that the main effect of this, too, was on soil moisture, but in the opposite sense to that of harrowing. By pressing the soil together, it was thought, the water-film was made more continuous, and the upper layers of the soil would draw quickly on the stores of water below. However, we now know that this effect is of little importance. The chief benefit of rolling is simply mechanical. It presses the soil more closely around the roots, and so helps their root-hairs to get into contact more easily with the water-film and water-rings.

Early and Late Soils

There is another important fact about the water in soil: it influences the temperature of the soil. It does this in two quite different ways. One is by evaporation. We saw in Chapter IV of "Simple Science" that evaporation uses up heat. It takes energy to turn liquid water into water-vapour, and the energy must be supplied in the form of heat. If water evaporates from a field, it will take heat from the soil, or prevent it warming up as much as it otherwise would. This may have a measurable effect on the temperature of the soil, for evaporating water uses a good deal of heat. The amount of heat needed to turn one pound of water into vapour is enough to raise the temperature of liquid water by 1° F., and of the same weight of dry soil by 5° to 7° F.

In Part II of "Simple Science" we also explained how moving air had much greater evaporating power than still air. So wind will keep soil cold. As we saw there, all living things except warm-blooded animals live and work and

grow faster at a high temperature. A rise of 6° to 8° F. may make a plant grow half as fast again. Furthermore, below a certain temperature, plants will not grow at all.

This is one of the reasons why gardeners and farmers plant windbreaks. It is not the direct force of the wind that is usually harmful, but its evaporating power. This acts both on the plant as it transpires water, and also on the soil.

In the spring, the soil has to warm up gradually from its winter chill before plant growth can begin. We have just explained how the activities of plants are slowed down to nothing at a certain temperature. This minimum requirement is different for different kinds of plants, but for most British crop-plants it is about 0° to 5° C. (32° to 41° F.); the optimum is from 25° to 30° C. The most obvious way of seeing this is with the germination of seeds. Take a number of seeds in winter—beans or peas will do very well—and plant them in pots of moist soil or sawdust after soaking them for a day, and then put the pots so as to be at different temperatures—one exposed out of doors, one in an unwarmed outdoor shed, one in a cool room, another in a warm room. Of course it would be a better experiment if you could arrange for exact temperatures, but these demand elaborate incubators with temperature-regulating machinery like those described in Chapter V of Book II. However, if you want to be more accurate you can have one pot surrounded by crushed ice, another in a refrigerator if there is one available, another surrounded by flowing water from a tap, which has a fairly constant temperature, and so on. You will find that in cooler surroundings the seeds after germination show much slower growth, both of shoot and root; but below a certain temperature they will not germinate at all. If you also try with maize seeds, you

will find the same thing, only these need a rather higher temperature before they can germinate; while some seeds, like melon pips for instance, need a very much higher temperature.

There are other factors which affect the germination and the growth of plants, but soil temperature is one of the most important. So you see that the rate at which the soil warms up in spring is very important. Until it gets to a certain temperature, the roots of the plants cannot begin to work, and after that the rate of growth of the crop is largely dependent on how actively the roots work, and so on the soil temperature. Also, as we shall see later (p. 212), soil temperature is important because it influences the rate at which bacteria in the soil work to provide the plant-food which the roots of the crop can use.

The amount of water in the soil has an influence upon this rate. To understand this properly we must consider what is meant by specific heat, to explain which we will go back to our experiment in Chapter IV of "Simple Science," Part II, where we compared the effect of putting a pound of lead, at the temperature of boiling water, into a pound of water at ordinary temperature, with the effect of putting a pound of boiling water into a pound of water at ordinary temperature. The lead only warmed the water slightly, while the boiling water made it extremely hot, and we concluded that the water must contain much more heat than the same weight of lead.

If we want to do the experiment properly, we must carefully take the temperature of the water with a thermometer before and after putting in the lead, giving the lead time to share its heat with the water, and stirring with the thermometer before we take the second temperature.

The kind of figures which we shall get, with a pound of water and a pound of lead, are as follows:

Temperature of lead	100° C.
Temperature of water before putting in lead	15·0° C.
Temperature of water after putting in lead and stirring	17·7° C.

Then we can argue as follows: 1 pound of lead falling $100 - 17{\cdot}7 = 82{\cdot}3°$ has given out enough heat to raise the temperature of the same weight of water through $17{\cdot}7 - 15 = 2{\cdot}7°$. Now since the heat given out in falling through $82{\cdot}3°$ must be the same as the heat required to raise the temperature through $82{\cdot}3°$ we can say that the same amount of heat that raises 1 pound of lead through $82{\cdot}3°$ will raise the temperature of 1 pound of water through only $2{\cdot}7°$.

We can put this another way. The heat required to raise 1 pound of lead through 1° is only $\frac{2{\cdot}7}{82{\cdot}3}$, or about $\frac{3}{100}$ths of that required to raise 1 pound of water through 1°. We call the heat required to raise a certain mass of any substance through 1°, compared with that required to raise the same weight of water through 1°, the specific heat of a substance, so that we can say that the specific heat of lead is about ·03. If we did the same experiment with copper, we should find the specific heat of copper to be about ·09, or the heat required to raise 1 pound of copper through 1° is only about $\frac{1}{11}$th of that required to raise 1 pound of water through 1°. No ordinary substance requires as much heat to raise its temperature by 1° as does water, so that specific heats are always fractions, less than 1.

Now the specific heat of the solid parts of the soil is low, only about $\frac{1}{5}$. The amount of water present is, there-

fore, the most important thing in considering how much heat will warm the soil, or, to put it another way, how long the soil will take to warm up when a certain amount of heat is given to it by sunshine, say.

If the soil contains much water, it will take longer to warm up than if it has less water. We have already seen that clay holds more water than sand; so a clay soil will be slower in warming up in early spring, and colder in late spring, than a sandy soil. This is what farmers mean by calling clay soils "cold" or "late": they give a late crop because they warm up so slowly.

However, specific heat works both ways: it applies to cooling as well as to warming. So at the end of the season, when the sun is less powerful and the average air temperature is getting lower, the clay cools down more slowly than the sand. It is only true to call clay soils "cold" in the spring.

This is one important consequence of the differing amounts of water in soils. However, there is another. We have seen that because sandy soils have less water, they warm up more quickly than clay. But they also grow dry more quickly, partly, of course, because there is less water in them, and partly because they are warmer, for, as we saw in Part II of "Simple Science," evaporation goes on more quickly the higher the temperature is. Now it is a fact that a shortage of water will make most plants flower and fruit earlier. If there is plenty of water, the leaves and stem and roots will go on growing longer and the whole plant will be bigger and more luxuriant. The crop of seed it finally produces will generally be a good deal heavier than the crop from the smaller plant in dry conditions: but the dry plant sees to it that it shall have some seed at any rate. It is better to flower prematurely and have less

seed than to run the risk of being killed before producing any seed at all.

Accordingly the crop on sandy soil will get an earlier

FIG. 92.—*Much moisture encourages growth but delays ripening. Two samples of wheat grown in moist (left) and dry soil (right); the wheat in the drier soil is not so tall, but has already produced ripe ears.*

start, and will grow faster, but in any save very wet years the plants will be forced to form flowers and seeds before they are of full size, and so the harvest will be smaller. You

might think then that with crops about which there was no hurry, like grain, it would be an advantage to use the latest possible soils, so as to get the heaviest possible crop. However, there you run another risk—of the crop being so late that the plants are killed by an early autumn frost before the ears are ripe. In each case the farmer has to balance risk or disadvantage against advantage. For some crops, like spring vegetables, new potatoes, certain fruits, and so on, where the earliest consignments get the best prices, he will use sandy soils, even though these, as we shall see later, are less rich in plant food, and so he has to spend more money on artificial fertilisers. He will also be willing to spend more money on making windbreaks to prevent the wind chilling the soil. Here the advantage of earliness outweighs everything else. For most crops, however, the maximum yield with the minimum risk is got in a good loam—not too early-drying like sands, not too late like heavy clays. There are other disadvantages about clay soils. They are harder to plough, and they are more easily water-logged and need more draining.

Draining is necessary for many heavy soils if they are not to be water-logged, at any rate in their deeper layers. If this happens, the roots of the plants will be unable to grow down into the water-logged layer, so that the plants cannot tap the water and plant-food in those layers and use them for their growth. The usual way of draining land is to dig a number of trenches, all sloping gently in the same direction, and to lay sections of unglazed earthenware pipes or bent tiles along the bottom of them. After this, the earth is put back in the trenches. The sections of pipe need not be joined: so long as there is an open channel, water will drain into it not only from above but from some distance on either side, and will steadily flow away. Sometimes

deep open ditches have to be cut through the country into which the field drains can discharge, and in very flat regions, like the Fens and parts of Holland, the water has to be got rid of out of these ditches by being pumped into rivers.

The most famous example of what drainage can do to improve land is seen in the Fens of East Anglia. This

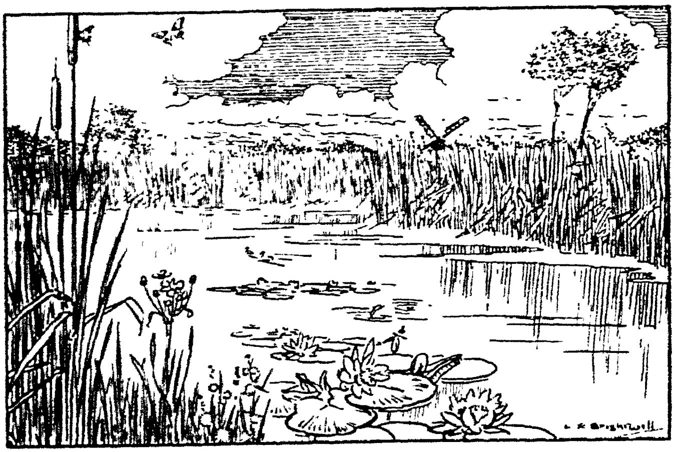


FIG. 93.—*Undrained fenland: a scene in Wicken Fen, Cambridgeshire, where pools and reedy marshes still abound.*

huge area, nearly a thousand square miles in extent, was for centuries a great expanse of reed-grown marsh and swamp, with a few "islands" of higher land rising out of it. Draining was begun in the reign of Charles I, and finished over practically the whole area two centuries later, and the fens are now one of the richest agricultural regions in the world. Wicken Fen, near Cambridge, was never drained, and has been preserved to protect the rare

birds and insects and plants that live in the marshes. If you have a chance of visiting it, you will realise what a change drainage has brought about. The Fen soils are different from most soils in being largely made of organic matter from plant remains; they differ from peaty soils, which are also mainly organic matter (p. 162), in not being acid. For these reasons they are unusually fertile: but they could not have become fertile soils without having been drained.

A great deal of wet land in different parts of the country was tile-drained in the middle of the nineteenth century; but there is still much undrained land that could be improved by draining. Unfortunately, trenching for draining is very expensive. However, a new method has been invented for draining very heavy clay soils, by dragging a "mole" of steel through the soil a certain distance below the surface. The hole it makes stays open for a long time and acts as a drain.

The Effects of Lime: Ploughing

Finally we must say a word about lime. There are different chemical substances known as lime, but in the soil the usual form is carbonate of lime or calcium carbonate ($CaCO_3$), the material of chalk. When farmers speak of "lime" they mean either carbonate of lime or some other form of lime, like quick-lime, which soon turns into carbonate of lime if spread on the soil.

Why do farmers add lime to their land? If you look at the fields on which lime is being spread, you will almost always find that they are fields with a clay soil, not those of sand or light loam. This suggests trying an experiment to see if lime has any obvious effects on clay. The chief differences we have already found between

clay and sand are in the size of the solid particles: the other differences, for instance in the degree to which they absorb and hold water, are consequences of this. So first we may try the experiment we made before, of seeing how much water runs through soil, but this time we will put in one funnel a layer of untreated clay soil (not puddled) and in the other a layer of the same material with which a little powdered lime has been mixed. The result, you will find, is that the limed clay lets water through much more easily.

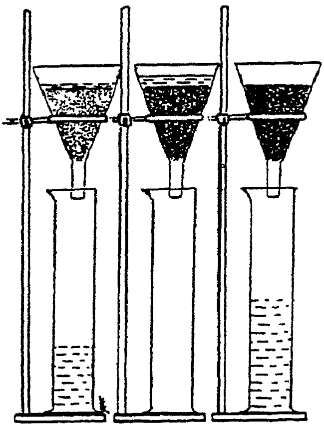


FIG. 94.—*Adding lime to clay makes it let water through more easily. Water was poured on to untreated clay (left), puddled clay (centre), and limed clay (right). No water passed through the puddled clay. The limed clay let much more pass than did the untreated clay.*

Or you can puddle a layer of clay in two funnels, sprinkle some powdered lime on one funnel and then pour water in. The untreated clay will allow no water to pass: but the limed clay soon begins to let water leak through. If you prefer you can mould little cups out of ordinary clay and limed clay: you will find that the one will hold water, the other will not.

Again, if you knead up a piece of clay and an equal-sized piece of limed clay (add to the clay about 5 per cent. of its weight of lime) you will find that the feel of them is quite different: it is much easier to model the untreated clay. If you make two equal-sized blocks out of the treated and untreated clay and then bake them, you will

find that the untreated clay makes a nice hard brick, while the block of treated clay is brittle and is easily crumbled to pieces.

In every case, you will see, the limed clay behaves more like sand. This ought to mean that limed clay has bigger particles than untreated clay. That this is actually so you can prove by a very simple experiment. Rub up some clay with water and fill two jars with the muddy-looking liquid that results. Then stir in some lime-water to one of the jars. In a short time it will clear and all the solid matter will have sunk to the bottom, while the other jar stays cloudy. If you watch carefully, you will see that adding the lime causes the appearance of little flocks or lumps in the cloudy liquid, and these then sink. The lime, for reasons it would take too long to explain here, causes the tiny clay particles, which are almost invisible to the naked eye, to join together to make bigger particles, and these then, as we have explained on p. 167, will sink quickly instead of settling extremely slowly like the small particles. This process is known as flocculation.

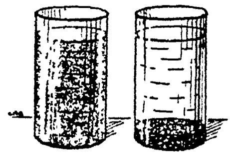


FIG. 95.—*Water with ordinary clay rubbed up in it stays muddy for a long time* (*left*); *if lime is added, the clay settles quickly and the water clears* (*right*).

So we see that by flocculating the tiny clay particles into larger grains, lime really does make a clay soil more like a loam in its properties. Now we can realise why farmers put lime on heavy soils. It helps drainage and aeration, it makes the soil much easier to plough, and it prevents the soil from cracking and forming big fissures when it dries or from forming lumps like brick.

Lime has other good effects. It helps to prevent

certain diseases of crops, like "finger-and-toes" in swedes and turnips, because it makes the soil alkaline, and the fungus which causes the disease only grows well in acid soils. It also helps the work of the bacteria we shall discuss in the next chapter, which unlock the reserve stores of nitrogen in the soil and make them available as plant-food. In this way it will often increase crop-yield. However, there is an old saw which says:

> "Lime and lime without manure
> Will make both land and farmer poor."

This is because the lime does not increase the total amount of plant-food in the soil, but only helps the plants to get at it. So if it is added year after year without other fertilisers, it will eventually exhaust the soil. However, we must put off saying more about the plant-food in the soil until the next chapter.

While we are talking of the size of particles in soil, there is one other point to be mentioned. Farmers know by experience what a good crop-soil should be like after it has been cultivated and is ready for sowing. They speak of a "good tilth" or a "poor tilth." If you get some soil from a cultivated field which the farmer says is good tilth, break up a little of it gently and look at it with a lens, you will see that it consists of tiny lumps mostly about a millimetre across. These are what the soil expert calls "compound particles" of soil. They are made of the ultimate fine particles loosely joined together. The spaces inside them are very small compared with the spaces between one compound particle and another. In a good tilth most of the water is in these little inside spaces. So the compound particles are rather like sponges and act as reservoirs of water, while the bigger spaces

between them serve chiefly for aerating the soil (Fig. 90). The right balance between the amounts of soil-air and soil-water depends on the size of the compound particles. In nature, they are produced by the weathering of the clods turned up by the plough. You can see this for yourselves by taking a biggish bit of a freshly-ploughed furrow-slice in the autumn and leaving it out of doors on a board through the winter and spring. You will find that the sticky solid slab gradually breaks down into a "good tilth."

Now we are finding out what is the point of all the heavy work involved in ploughing. Ploughing destroys the remains of the old crop and any weeds there may be among it. It breaks up the soil and brings fresh layers to the surface. It exposes slabs of sticky solid soil to the action of air and water, heat and cold, and so causes them to weather into the small compound particles. This gives the soil the right capacity for holding water and admitting air. It also allows bacteria to break down the plant-remains in the soil and to convert them and other substances into plant-food available for crops (see p. 211). Ploughing is the

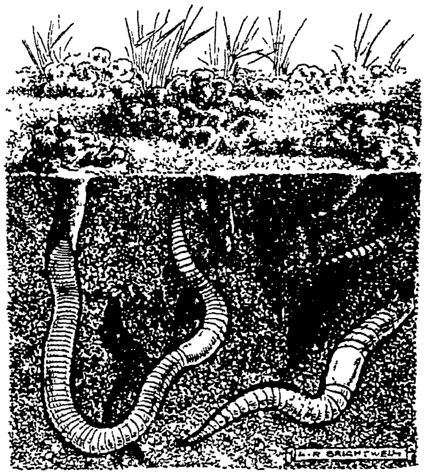


FIG. 96.—*Earthworms in their burrows in the soil. They eat soil, and pass the undigested grains of earth to the surface in the form of "worm-castings."*

most important operation in agriculture: without ploughing no farmer could raise a crop that would be worth his trouble.

Let us also remember that earthworms are a natural ally of the farmer and the gardener. Their burrows help to aerate the soil. They spend a great deal of their time eating their way through the soil in order to digest out of it the vegetable debris which it contains; and this grinds the soil up very fine. Furthermore, they throw up at the surface all the undigested soil that has passed through their bodies, in the form of worm-castings; by this means they are constantly bringing soil from the deeper layers up to the air, where it will weather more quickly and release its stores of plant-food. So in some respects earthworms act like thousands of miniature ploughs, helping to cultivate the soil. Charles Darwin wrote a book about earthworms which is well worth reading, to show you how interesting these little creatures are and how useful their work is to us.

Plant-remains in Soil

Besides water and rock-particles and air, soil contains other important things. One of these is what is called humus, which is produced by the decay of bits of vegetable material in the soil. If you bury a pile of hay or straw or dead leaves a few inches below the surface in a ploughed field or a garden, it will slowly rot, turning brown as it does so. In time, all traces of the original structure of stem or leaf are lost, and nothing is left but an almost black mass. The same thing happens when bits of plants fall naturally to the ground, or get ploughed in. The resultant formless black material is what we call humus. Sometimes humus is formed in large amounts, as in woods where there are

great quantities of dead leaves; then it is called leaf-mould. Gardeners often make masses of leaf-mould by piling up dead leaves and letting them rot slowly through the winter.

Humus consists very largely of carbon, with some nitrogen and hydrogen. Accordingly it can be burnt, unlike the solid particles in a soil. If you heat a soil to red heat, it will lose more weight than if you just dry it in an oven. That is because the humus has been burnt up as well as the water driven off. When the heated soil cools again, you will see that it has lost its dark colour: it was the humus which made it dark. Usually it turns yellowish or reddish, as pure clay does when it is baked: this is due to the traces of iron in it being burnt to form oxides of iron. You can show this in another way. In Part II of "Simple Science" we explained how burning was due to the rapid combination of oxygen with a substance. If you can get oxygen to combine with the substance in less violent ways, you will not get such a burst of heat, but the same kind of chemical fate will overtake the substance. Hydrogen peroxide (H_2O_2) very readily gives up some of its oxygen to combine with other substances. If you stir a small amount of soil into five or six times its weight of hydrogen peroxide and gently warm the mixture, the oxygen set free from the peroxide will attack the humus. The soil gradually loses its dark colour. If you look at some of the soil particles under a microscope before and after the treatment, you will see that originally they were covered with a dark film, but that the hydrogen peroxide gets rid of this. As a matter of fact, the humus in most soils gets deposited as a thin layer on the surface of the solid particles.

The humus is an important source of the plant food in soil, so that in general black soils are rich soils for crops:

but to that we shall come back later. Here we must say something about soils in which plant remains do not break down in the same thorough way, but accumulate with very little decay. The soils in which this happens are the peaty soils we have already mentioned.

There are various kinds of peaty soils, and the reasons why plant-remains in them do not decay to such an extent as in ordinary soils are also various. Sometimes it is because the plant-remains themselves do not decay easily, as in pine-woods. Sometimes, as in the water-logged soil of the fens, it is because there is too little air and therefore too little oxygen. Sometimes, as in moorland peats, it is partly due to this reason, and partly to the fact that they are acid, and the bacteria which cause decay ("Simple Science," Part I, Chapter VII, and Chapter VI of this Book) do not live well in acid surroundings.

In any case, the result is that the shed leaves and dead remains of plants do not rot away year by year, but accumulate in layers.

Peat has also a great capacity for holding water. It absorbs it like a sponge, and will then swell a great deal. With peat-bogs on the side of a hill, long-continued rain may cause so much swelling that the peat may burst out and run down the hill like a river of soil, sometimes doing great damage. Nowadays most peat-bogs have ditches cut through them to drain the water away and prevent such dangerous overflows. Dried peat is often used on the floor of stables because of its power to absorb moisture.

Partly because of their acid reaction and partly because they are so easily water-logged, peat and peaty soils will support very few kinds of plants, and are no good for crops unless treated in some way. The best method for

making acid soil good for cultivation is to put lime on to it. This combines with the acid and neutralises it. So lime is useful to farmers in two ways: it can make heavy clay soils lighter, and it can make acid soils neutral or alkaline.

We have already learned a good deal about soils—how they are formed from rock; how they are constructed of air spaces, water films, and solid particles coated with dark humus; what are the differences between light and heavy soils, and their advantages and disadvantages to the farmer; and why peat is so different from other kinds of soil.

But we have learnt very little about the plant food in soil, and this is, of course, equally important with water and air for the growth of crops. This subject is so important that it needs a separate chapter.

CHAPTER V

AGRICULTURE

Plant Food—Manures and Fertilisers—Nitrogen and Agriculture—Soils, Plant-life and Scenery

Plant Food

GREEN plants get some of their food material from the air by means of their leaves, the rest from the soil by means of their roots. This is one of the basic differences between plants and animals. To-day the facts are so well known that we are apt to take them for granted; but it took two centuries of scientific experiment and discussion to establish them as facts.

We and all familiar animals take in all our food at one place—through the mouth. It did not seem "natural" that different food materials should be taken in at opposite ends of a plant, and the Greek scientists like Aristotle thought that plants obtained all their food from the soil.

One of the earliest experiments on the matter was made in the early part of the seventeenth century by a Belgian doctor called Jan van Helmont. By careful weighing, he showed that during the growth of a plant its solid parts (measured by its dry weight) increased more than the dry weight of the soil in which it was growing decreased. About a hundred years later, the Rev. Stephen Hales, an English clergyman, who was vicar of Teddington, proved definitely that this was due to the plant taking something from the air. We now know that this something is the carbon from carbon dioxide.

Accordingly the farmer has not got to worry over the

supply of carbon to his crops. So long as plants have access to light and air, they will be able to get as much carbon dioxide as they want, for the amount of carbon dioxide in the air is always about the same. The plant also gets from the air all the oxygen which it needs for respiration. However, while only the green parts of the plant are concerned with taking in carbon dioxide, the roots and root-hairs as well as the leaves must be in contact with oxygen. So in this case the farmer has to see that the soil is properly aerated, or else the roots will not grow and will not be able to do their work. On the other hand, he has never to provide extra oxygen: the supply in the air is inexhaustible. He is only concerned to see that the soil is not so water-logged or so tightly packed that the air does not penetrate.

With the other substances that the plant needs, the matter is different. They have to be absorbed by the roots in the form of water and of salts dissolved in water. Furthermore, the amount of them is not the same everywhere, and in some places may not be enough for full growth or even for healthy growth at all. This applies to the water needed by the plant, as well as to the salts. But we spoke about the water in soil in the previous chapter, and here shall only be dealing with the other substances taken up by the roots. Let us remember at the outset that these must all be in solution in the water-film of the soil if the roots are to be able to absorb them.

The most accurate way of finding out exactly what substances plants have to get from the soil is by means of what is called water-culture. Plants are grown with their roots, not in soil, but in a vessel of water to which given chemical substances have been added.

Chemical analysis of plant tissue shows that plants con-

tain, besides carbon and hydrogen, oxygen and nitrogen, small amounts of phosphorus, calcium, iron, sulphur, magnesium, potassium, sodium and chlorine. We know that the plant gets its carbon, hydrogen, and oxygen from air and water. We can then make up a solution with all the other elements present in it and see what happens when we leave one of them out.

A solution made up as follows will serve as a basis from which to start. To every 1,000 c.c. of water add:—

1 gram of potassium nitrate (KNO_3), supplying potassium and nitrogen;
½ gram of sodium chloride ($NaCl$), supplying sodium and chlorine;
½ gram of calcium sulphate ($CaSO_4$), supplying calcium and sulphur;
½ gram of magnesium sulphate ($MgSO_4$), supplying magnesium and sulphur;
½ gram of acid calcium phosphate ($CaH_4(PO_4)_2$), supplying calcium and phosphorus;
a trace of iron chloride ($FeCl_3$), supplying iron and chlorine.

You should then have a series of jars: it is best to wrap brown paper round the jars to keep the roots from bright light. One jar is filled with the solution made up as above. In the second, substitute potassium phosphate for potassium nitrate—here you deprive the plant of nitrogen in solution. In jar 3 deprive the plant of phosphorus by putting calcium nitrate for calcium phosphate. So you can go on, with "no potassium," "no sodium," "no chlorine," "no magnesium," "no sulphur," and "no iron" jars.

By these means you will find that chlorine and sodium are not necessary, but that the other elements are all necessary for proper growth. However, the absence of

each necessary element causes a different kind of disturbance to growth.

This is a very interesting experiment to make, but takes a good deal of time and trouble. Also for practical pur-

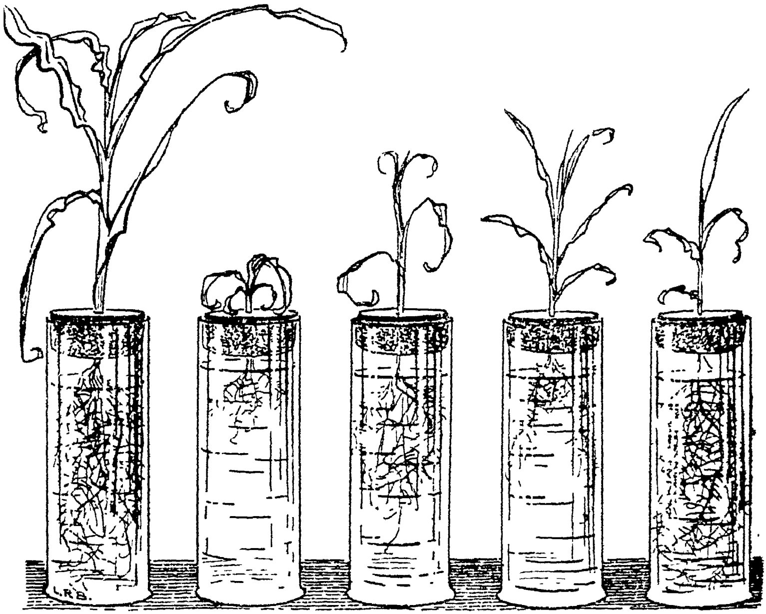


FIG. 97. — *Five plants of maize grown in water-culture. From left to right:* 1, *With all the elements needed for proper growth;* 2, *no nitrogen;* 3, *no calcium;* 4, *no phosphorus;* 5, *no potassium.*

poses we are interested only in the substances that are likely to be lacking or deficient in soils. Almost all cultivated soils (though not all pasture lands) have enough sulphur, magnesium, and iron in them. So the elements we have to think of are nitrogen, potassium, phosphorus,

and calcium. The most practical way of testing the effects of these is to grow plants in some soil which is known to be very poor, like almost pure sand, and adding different combinations of the mineral fertilisers or artificial manures which are to be found on the market for "improving" poor land.

However, before we go on to describe an experiment of this sort, we must say a word about manures.

Manures and Fertilisers

Farmers and gardeners manure land to increase the fertility of the soil. The original meaning of *manure*, which is derived from the French *manœuvre*, was simply to work by hand—in other words to cultivate the land. In this and the previous chapter we explain why working the soil increases its fertility. However, people no longer use the word in this sense. In the course of history, it was found that various natural substances added to land might help the crop. These are called natural manures. The commonest is farmyard manure, which consists of the dung of animals mixed with plant remains like straw; but rotted seaweed is often used near the sea coast, and ground-up bones, the waste material from wool and cloth manufacture, refuse parts from meat and fish, guano (which consists of the accumulated droppings of sea-birds or bats—see p. 139), and dried blood are all sometimes employed.

When people began to study plant growth scientifically, they at first thought that plants could only get their nitrogen from organic compounds. In nature they were supposed to get nitrogen directly from humus, and so if manure was used, it was thought necessary that it should consist of animal or plant remains.

It was not until about the middle of the nineteenth

century, with the progress of chemistry and of plant physiology, that the idea of manuring land by adding mineral substances was seriously put forward. Thanks to the great chemist Liebig in Germany and the patient experimenters Lawes and Gilbert at Rothamsted in England (whose work was begun in 1843 and is still being continued on the same land) it was discovered that the fertility of soils could really be increased in this way. Farmers in earlier ages would have laughed at the notion

FIG. 98.—*The yield of swedes: left, from a rich soil with no extra fertilizer; centre, from a neighbouring plot to which ten tons of farmyard manure to the acre has been added; right, from a plot to which the same amount of farmyard manure has been added, and also* 8 *cwt. of chemical fertilisers containing nitrogen, phosphorus, potassium, and magnesium.*

that adding lumps of mineral matter could be any good, but to-day the bulk of manure consists of mineral fertilisers. Some of these come from natural deposits, like the nitrates of Chile, the phosphate-containing rock of North Africa, etc., but most of them are now made artificially in chemical factories.

Now we can go back to our series of pots which contain different mineral salts added to sand: we know that in these laboratory experiments we are doing the same

sort of thing that farmers do every year on a big scale with their land.

Oats and mustard are good plants to try. Sow seeds of these in a series of pots of poor sandy soil. The results will be more definite if you first wash the sand thoroughly to get rid of any plant food, in the shape of mineral salts, which may be present. Add to the pots different combinations of three artificial manures, one supplying nitrogen, one phosphorus, and one potash—for instance, nitrate

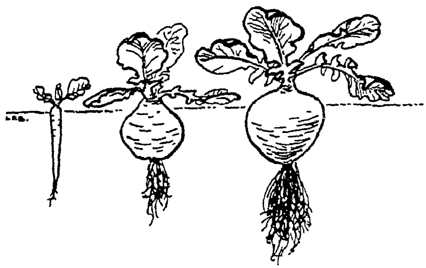


FIG. 99.—*Three turnips from neighbouring plots. Left, with no manure; centre, with manure containing phosphorus and potassium, but no nitrogen; right, with manure containing nitrogen, as well as phosphorus and potassium.*

of soda, superphosphate, and potassium sulphate. In one pot put no manure, in one all three kinds, and in three others put one of each kind of fertiliser separately. If you like you can also try the effects of the fertilisers two at a time.

You will find that the seedlings in the unmanured pots make the poorest growth, while, as you might expect, the best growth takes place in the pots with all three fertilisers. Of the elements used separately, nitrogen has the largest effect: without nitrogen, the plants will make

no further growth after they have exhausted the stores of reserve food in the seeds.

Experiments of this sort can also be carried on through a whole season with different kinds of plants, different soils, and different quantities of the various mineral substances. In experimental farms they are usually done in small plots of ground instead of in pots. From tests of this sort a number of interesting results have been gained. For instance, it is found that extra nitrogen causes plants to grow more luxuriantly, with deep green foliage, but that it delays ripening (as we found also for abundant moisture, Chapter IV, p. 183). Lack of nitrogen gives stunted plants with yellowish leaves. Extra phosphorus, on the other hand, usually makes for early ripening, and also for good root-growth in young plants. Potassium helps to protect plants from disease, while excess of nitrogen with too little potassium often makes them more susceptible.

One of the great uses of phosphorus is to encourage the growth of good pasture. A rough pasture with coarse grasses can often be turned into a rich meadow, with plenty of clover and fine grasses, by a fertiliser containing phosphorus.

With regard to soils, most clays are benefited by phosphorus and most sandy soils by potassium. But each soil needs to be analysed and tested separately. Furthermore, different crops have rather different requirements. For instance green crops and root crops, like cabbages and turnips, from which the farmer wants rich growth before flowering and seeding, can stand a great deal of nitrogen. On the other hand, with crops where the valuable part is the seed, like wheat or peas, too much nitrogen may delay flowering and seeding too long. You can see

how the growth of scientific knowledge about soil chemistry and plant growth helps the farmer.

To get the best practical results, it is necessary to have a proper balance between the amounts of nitrogen, phosphorus and potassium. A given amount of nitrate, for instance, will have different effects according as it is supplied alone or together with phosphate. The right proportion will differ according to the climate and the kind of soil. Only long-continued experiments in many different situations over many years provide a safe guide to practice.

Another point to remember is that the extra crop-yield to be got by means of fertilisers will not simply go up in direct proportion to the amount of fertiliser added. As we approach the limit of what the plant can do in the way of growth and yield, the addition of the same amount of fertiliser has less effect. The farmer gets a diminishing return for his money. So, in practice, the amount of fertiliser to be added will depend on what is most profitable, taking into account not only amount of yield, but also the price that has to be given for fertiliser and the price to be got for the crop.

There is one other thing about the chemistry of soils which is important, and that is its effect on animals. Animals like sheep and cattle eat grass, and the grass draws its mineral food from the soil. Accordingly in the long run the sheep and cattle too get the minerals they need out of the soil: if there is not enough of a particular mineral in the soil, it must be supplied by the farmer, otherwise the beast will not grow as well as it ought to, or may even fall ill and perhaps die. Wild animals will often go long distances to salt licks—places where solid salts are found or the soil is rich in mineral salts. But this is not possible for tame cattle and sheep.

The chief mineral elements which are likely not to be present in sufficient quantity for grazing animals are phosphorus, iron, and calcium. In parts of East Africa there is a lack of iron, and cattle there used to fall sick in large numbers. In the west of Scotland much rough

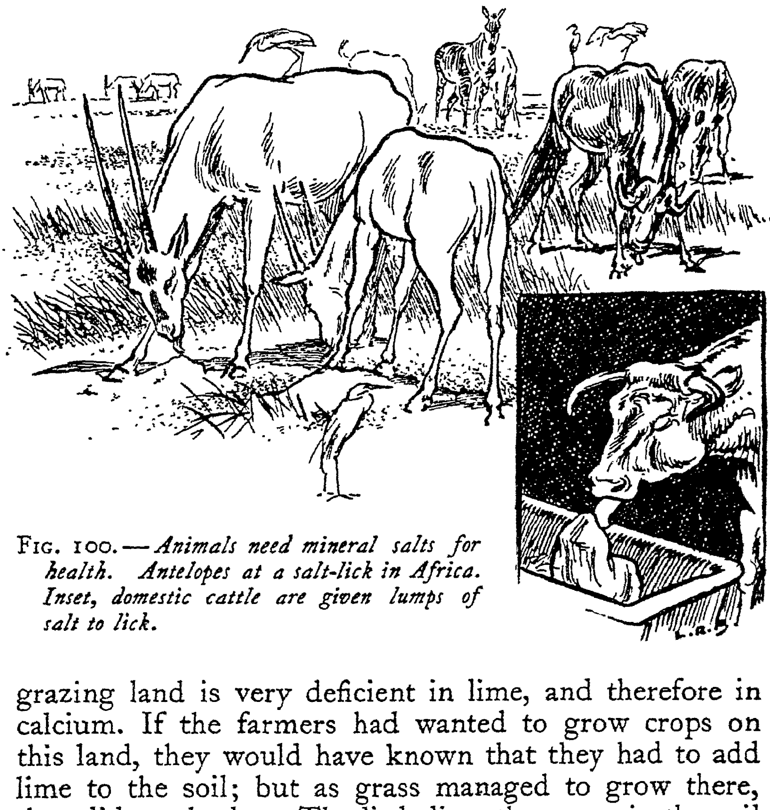


FIG. 100.—*Animals need mineral salts for health. Antelopes at a salt-lick in Africa. Inset, domestic cattle are given lumps of salt to lick.*

grazing land is very deficient in lime, and therefore in calcium. If the farmers had wanted to grow crops on this land, they would have known that they had to add lime to the soil; but as grass managed to grow there, they did not bother. The little lime there was in the soil was gradually taken out by the sheep, being deposited

especially in their bones, and not put back into the ground, until eventually there was a real deficiency of lime and the sheep were not doing at all well. When it was discovered that this was due to the grass being so deficient in calcium, lime was added to the soil, and this has allowed the sheep to grow bigger and more quickly and to be free from disease.

Lack of phosphorus is perhaps the commonest trouble. This again is needed for bones. Without enough phosphorus, the bones are of poor quality, and growth is stunted.

It is really just as important to add fertilisers to pastures as to cultivated land. The principle is the same in both cases—the farmer is taking nitrogen and phosphorus and calcium and other elements out of the soil in his crop or in his beasts, and unless he puts them back, there will be a shortage. Adding nitrates to pastures may induce a more luxuriant growth of grass, and may enable an acre of pasture to support more beasts. By treating pastures with proper fertilisers, it would be possible to prevent a great deal of disease in sheep and cattle, and to grow perhaps twice as many beasts in Great Britain as there are now.

So far we have been talking about chemical fertilisers, because with them it is easier to disentangle the effects of the different chemical substances needed for soil fertility. But farmyard manure is still one of the most important fertilisers, and we must say a word about it. Farmyard manure contains all three of the elements we have seen are of most value in fertilisers—nitrogen, phosphorus and potassium. But it contains only rather small quantities of them—only about twenty pounds in every ton. So if the supplying of these substances was all

that was done by farmyard manure, it would not be of much value compared with mineral fertilisers. However, it has other important effects as well. It contains a great deal of plant remains, and these, as they break down into humus, help a light soil to hold moisture better: so farmyard manure is valuable on dry sandy land. Leaf-mould is valuable in the same way in gardens—it adds plant-food, and helps light soil to retain water.

On the other hand, farmyard manure also contains substances which act on clay in the same sort of fashion as lime (p. 187). So it will make clay soils easier to cultivate and less likely to grow water-logged. It thus improves the texture both of very light and very heavy soils. Finally, it may have a slight effect on soil temperature. You all know how a manure-heap will steam. This is because it is heated by the slow burning which accompanies decay. This heating effect will still go on when it is spread on the soil, but will not be enough to make any practical difference unless it is applied in large amounts, as is sometimes done in gardens. For these various reasons combined, farmyard manure is still one of the farmer's staple aids to increased soil-fertility; but we now know that on most land it needs to be supplemented with mineral fertilisers to obtain the best results.

Nitrogen and Agriculture

There is one curious fact we must mention here. Most plants grown in pure sand with phosphorus and potash added to it, but no nitrogen, make very poor growth. But this is not true of clover: this will grow almost as well as when nitrogen, phosphorus, and potash are all added. We know that clover has no less nitrogen in it than wheat or turnips. So it must be getting nitrogen

from somewhere. If it is not getting nitrogen from the soil, it must presumably be getting it from the air, which you will remember is four-fifths pure nitrogen gas. This is, as a matter of fact, what is happening. If you look at the roots of a clover, you will see that they are covered with

FIG. 101.—*Some leguminous plants, which can "fix" nitrogen. From left to right: pea, runner bean, white clover, kidney vetch.*

curious little swellings or nodules (Fig. 152, p. 292). These nodules are full of a special kind of bacteria (see "Simple Science," p. 27, which, when associated with their host plant, have the power of using nitrogen gas and building it into proteins, whereas green plants by themselves can only use nitrogen in the shape of salts like

nitrates. These bacteria can fix the nitrogen of the air (see Chapter III, p. 140).

The bacteria and the clover plant live together in a kind of partnership. The clover, like all green plants, is good at building up carbohydrates, such as sugar and starch; the bacteria are good at building up nitrogenous substances. Each hands over to the other some of its surplus. That is why the clover can grow where there is little or no nitrogen in the soil.

These nodules with their "nitrogen-fixing" bacteria are found on most leguminous plants—that is to say, plants of the pea tribe, like clovers, vetches, peas, beans, lupins, or lucerne.

For at least two thousand years it has been known that a leguminous crop was often successful in restoring fertility to land, but it is only during the last fifty years that the reason for this has been discovered. Of course an ordinary crop is a drain on the nitrogen of the soil. Both the grain and the straw of wheat or barley, for instance, contain a great deal of nitrogen, and all this has been sucked out of the soil by the plant. After a time, there is not enough nitrate for a good crop. If lupins or clover are then planted, and later ploughed in, they will have taken a great deal of nitrogen out of nitrogen gas in the air and brought it into the soil where next year's corn can use it.

This method is still sometimes practised: but to-day, when mineral fertilisers are cheap, these are generally employed instead, and the farmer has not to spend a whole season in using leguminous plants to store nitrogen for him in his land.

This knowledge about the nitrogen-fixing powers of leguminous plants being due to bacteria is now being used to improve farming in Britain and other parts of Europe.

The leguminous plant called lucerne or alfalfa is a good forage crop, especially valuable on light soils on account of its wonderful root-system, which penetrates very deep and so enables it to resist drought. However, there were some regions where it could not be made to grow. It was eventually found that this was due to the fact that the soil in these regions did not have any of the right nitrogen-fixing bacteria in it. Now a method has been devised for mixing lucerne seed with a culture of the bacteria before sowing and so making sure that the lucerne seedlings will have plenty of their nitrogen-fixing partners to help them in their growth.

FIG. 102.—*Alfalfa or Lucerne. Left, a single spray, showing the leguminous (pea-like) flowers. Right, showing the root penetrating many feet deep into the dry soil.*

Now we can go back to the soil. We have seen that nitrogen in the form of nitrates is necessary for plants, and also that adding it to the soil in fertilisers will cause an increased growth in most crops. On the other hand, experiments carried out at Rothamsted have shown that wheat grown year after year on the same plot of land for nearly 100 years is still able to make about the same crop as at the beginning—a very moderate crop, only about twelve bushels to the acre, but the same steady average. With our knowledge of the amount of nitrogen in the wheat grain and straw it can be calculated that during the

seventy-two years 1843-1914 the wheat took about 1,200 lbs. of nitrogen per acre out of the ground. Yet when the soil was chemically analysed in 1914, it was found that the top nine inches of it still contained 2,570 lbs. of nitrogen to the acre. As even a bumper crop of wheat will not take more than 100 lbs. of nitrogen out of an acre, it is clear that there was plenty of reserve nitrogen still in the soil. Why was it that the crops were so small, much smaller than if nitrate had been added?

The answer must clearly be that most of the nitrogen is locked up in some chemical form in which the crop cannot use it, and is only unlocked little by little, by being slowly turned into nitrates. This is like the difference between capital and income. A man might have a thousand pounds capital, but not be allowed to touch this under the terms of a will. Then all he could use would be the income, from investing the capital in some business. The interest which he got from the capital would vary according to how the business was going—one year he might only get thirty pounds income, another year sixty pounds. The capital nitrogen which plants cannot touch is in the form of humus and other plant and animal remains. Before it can be used as income, these organic compounds must be broken down and combined with oxygen: the carbon in the plant remains eventually comes out in carbon dioxide, the hydrogen in water, and the nitrogen in nitrates.

What is there in the soil which works at the business of turning the stores of capital nitrogen into the income nitrogen which plants can use, converting organic nitrogen into nitrates? The answer is rather a surprising one. It is: certain kinds of bacteria that live in the water film round the soil particles.

THE SOIL'S MICROSCOPIC LIFE

More than fifty years ago it was discovered that the formation of nitrates in soil would stop temporarily if the soil were treated with chloroform vapour or antiseptics, or heated above 55° C.; and would be permanently lost if the soil was heated to a little above the temperature of boiling water. This pointed to something alive being concerned, and later the bacteria responsible were artificially cultivated, so that it was possible to find out exactly what they do.

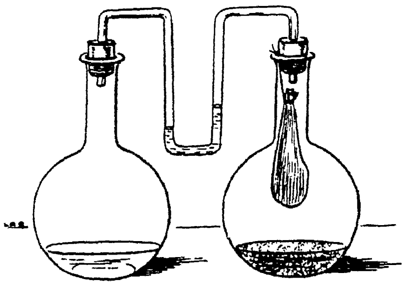


FIG. 103.—*Soil contains something alive. A bag of soil is hung inside one of two flasks. The flasks are connected by a tube with water in it, and both contain a little lime-water. After a few days, the lime-water in the flask with soil turns milky, showing that CO_2 has been given out; and the water in the tube has moved towards this flask, showing that some air has been used up.*

This discovery helped to explain a great many things in farming practice. It had long been known, for instance, that if you bring the deep subsoil layers to the surface, crops will at first hardly grow on them, and it takes a long time before they can be turned into fertile soil. This is partly because there is little organic nitrogen stored in them, and partly because they contain none of the nitrate-making bacteria.

Again, bacteria are living things, and for their activities need a certain degree of warmth; what is more, the higher the temperature is raised up to a certain limit (about 25° to 30° C.), the harder they will work. Sometimes, if there is

a cold drying wind in spring, a crop of growing corn will turn yellow and make very poor growth. This seems to be because the evaporation has chilled the ground so much that the nitrate-making bacteria are put almost or quite out of action. (Below about 5° C. they are not able to work at all, but remain inactive.) The growing corn uses up all the available nitrate, and turns yellow for lack of nitrogen. So here is another advantage of what farmers call "warm" soils—their higher temperature in spring not only stimulates the crop to grow more quickly, but provides more nitrate, which it can use for its growth.

These bacteria again, like other living things, need oxygen and water. The oxygen they must get from the air spaces in the soil, the water from the water film in the soil particles. So everything we have said about the need for air and water in the soil is true for the bacteria as well as for the roots of the crop: it is a double need. But the need of air and moisture goes on even when there is no crop on the land. Without either oxygen or water, the bacteria could not get on with their job of building up a good store of nitrates ready for the next crop to use.

This explains why land is often cultivated even when there are no crops on it. In old times, this was the regular practice. Every so many years—usually every third year—land was allowed to "lie fallow," as it is called. No crop was planted on it, but it was ploughed and worked as often as possible during the season. The cultivation broke up the soil and aerated it thoroughly, and so provided the best conditions for the bacteria to make nitrates.

The introduction of "root-crops" like turnips and swedes has altered the system. These were unknown in the middle ages, and only became generally grown towards

the end of the eighteenth century. They provided a crop of animal fodder which the old system did not, and so enabled farmers to keep many more cattle through the winter, instead of killing most of the stock each autumn and preserving their flesh as salt meat for winter eating. But the rows of turnips are far apart, so that the farmer can still cultivate the soil between the rows while the plants are growing, which is impossible with wheat and other cereals. This change in agricultural practice was largely due to the Englishman William Cobbett, who made a

FIG. 104.—*An Amœba from soil, about $\frac{1}{1700}$th of an inch across, showing its changes of shape. In the lower row it is seen engulfing a soil bacterium.*

survey of British farming in the early nineteenth century.

If you keep an eye on a field of growing turnips, you will find that the land is thoroughly and repeatedly cultivated during the warmer part of the year: this encourages the nitrate bacteria so much that in spite of the nitrates the turnips take out of the soil, plenty is left in. In fact, by growing root-crops every third year most of the land is allowed to enjoy the advantages of the old

system of fallowing, even though a useful crop is being produced at the same time.

Much more recently it was discovered that the soil had other microscopic inhabitants besides bacteria. Bacteria are plants, and these other creatures are animals, and eat the bacteria. They are mostly of the type known as Amœba. These are an extremely simple kind of animal. An Amœba consists of a little blob of transparent semi-liquid substance which can move in any direction by thrusting out part of itself as a sort of temporary limb. It has no mouth, but simply surrounds its food by flowing round it. There are other kinds of microscopic soil animals too, but they all belong to the group of animals called Protozoa, which means "primitive animals." These consist only of a single cell or unit of life, while all familiar animals and plants are made of millions or even billions of cells.

There are astonishing numbers of these creatures in soil. An average figure for good fertile soil would be about 3,700 million bacteria and rather over three quarters of a million protozoa for each gram of dry soil. Of course they are all very tiny—it would take about 28 billion of the bacteria to weigh an ounce!—but even so the living matter in soil in the form of these microscopic animals and plants, not counting big animals like earthworms or the roots of ordinary plants, comes to about 2½ tons per acre in the top six inches of the soil—about four parts per thousand of the weight of the soil.

If soil is heated almost to the boiling point of water for a short time, it is found that after a short interval its fertility is increased, and this increased fertility is due to its power of producing nitrates becoming higher. This increased fertility may last for at least a year.

The reason for this, it seems, is that the heat kills all or almost all the soil protozoa, while many of the bacteria shut themselves up in a tough coat and pass into a resistant state called a spore. In this condition they will resist the heat that kills the protozoa, and then will start growing and multiplying again when conditions become normal once more. The relation between the protozoa and the bacteria in the soil is something like the relation between lions and the creatures they prey upon, such as zebra and antelopes, in Africa. If you could kill off all the lions in a region, the zebras and antelopes would increase rapidly in numbers until lions began to wander in again from other regions.

Sometimes the conditions favour the protozoa more than usual. Then the bacteria are kept down to very small numbers, and accordingly very little nitrate is produced. This happens occasionally in rich greenhouse soils: market gardeners say the soil is "sick." In old days, "sick soils" had to be thrown away and new soil brought in and cultivated and manured until it was suitable. Nowadays, however, our knowledge about protozoa has suggested another method. It is possible to restore the fertility of such soils simply by heating them, which is much less troublesome and expensive.

Soils, Plant-life and Scenery

What we have said about soils helps us to understand many things about the countryside. In Britain, very often you will find grassland in the bottom of a valley and cultivated fields on the slopes. When this is so, it is almost always because the slopes are well drained, while the bottom is wet. Grass and rushes can stand more wet in the soil than crop-plants. Again, as you get higher

up above sea-level you will find less cultivated land and more grass: there is not much corn or roots grown above 600 ft. in this country, and very little above 800 ft. As you go still higher, there is less good pasture and more rough grazings and moor. This is because grass can stand more cold than crop plants, and the poor rough kinds of grass are more resistant than the richer varieties.

FIG. 105.—*A country scene. The cultivated fields are on the well-drained slopes, while the wet valley-bottom is given over to rushy pasture, and the exposed hill-top to wood.*

Woods are often seen on the tops of hills, where it is cold and exposed and not worth while cultivating the soil for crops.

Then, of course, different kinds of soils suit different kinds of plants. The wild plants are the most interesting to study in this respect. Sandy soils usually

have less water and are more liable to drought. So plants growing on these must arrange matters so that the water-current passing through them ("Simple Science," Part II, Chapter VI) is smaller than usual, or they would run the risk of wilting and dying. The water that passes through a plant evaporates into the air through the leaves: so plants adapted to grow on a sandy soil generally have small leaves. You can at once think of pine-trees, heather,

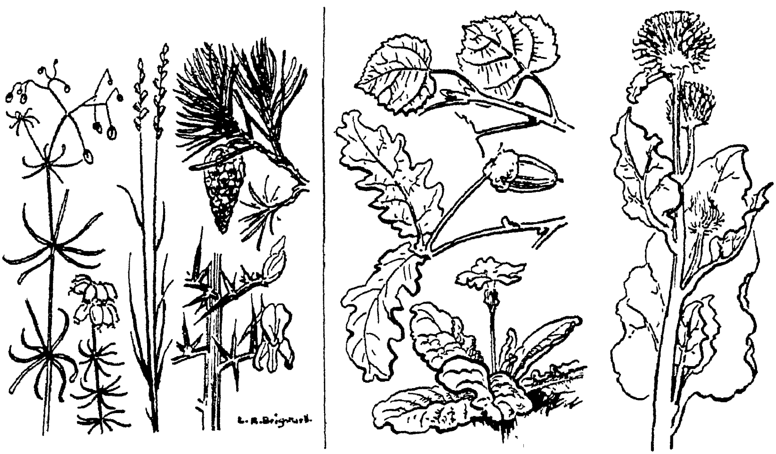


FIG. 106.—*Left, some plants from dry, sandy soils, with narrow leaves: spurry, heather, sheep's fescue, pine, gorse. Right, some plants from moist loam soils, with broad leaves: poplar, oak, primrose, burdock.*

and broom, and if you look you will find many other examples. There are not many of the ordinary broad-leaved trees to be found on sandy commons.

In clay, on the other hand, there is generally much more water, and here and in wet soils in general the plants can afford to have a bigger water-current and therefore

bigger leaves: think of docks and burdocks, primroses, and butter-burs. You will notice the same difference in size of leaves between the grasses of sand and clay soils.

Some plants, again, prefer lime in the soils, while others cannot stand it. If you see foxgloves or broom growing

FIG. 107.—*Some plants which tell you that there is no lime in the soil where they grow: broom, foxglove, rhododendron.*

wild, or azaleas or rhododendrons in a garden or park, you will know there is no lime in the soil.

If you live in the country, it is very interesting to make soil and vegetation maps of the region round your home. On one map you can mark the different kinds of soils—sands, loams, and clays, and whether they are dry, medium

moist, or wet. The geological map which you have already made (Chapter II) will tell you what kind of rock or

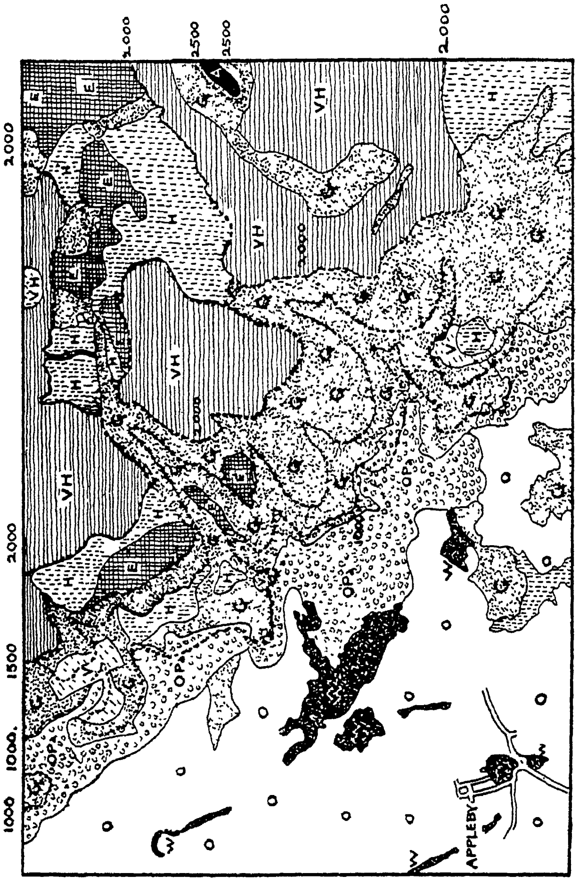


FIG. 108.—*A vegetation map. The country east of Appleby, including part of the Pennine hills. The* 1000-, 1500-, 2000-, *and* 2500-*foot contour lines are marked.* W, *woodland;* O, *lowland cultivation, with oats;* OPa, *pasture land, used for hay;* G, *natural grasses and grass-heath;* H, *moorland with heather, mostly ling, predominant;* VH, *moorland with bilberry and heather;* V, *bilberry predominant;* E, *upland bogs with cotton-grass;* A, *Alpine plateau, with peat and stunted mountain plants, including much moss and lichen.*

drift is at the surface: for plant life it is especially important to know where lime-containing rocks like lime-

stone and chalk are to be found. Then you can fill in on another map the distribution of cultivated land, good pasture, rough pasture, woodland, and waste lands like moors, sand-dunes or marshes. Finally, you can make maps for certain special kinds of wild plants—for instance, pine-trees, heather, cowslips, spurry, harebells, docks, anemones, meadowsweet, scabious, and so on. You will find that each kind has its own definite distribution, and in many cases you will be able to understand the reason for this.

Now we are in a better position to answer the question with which we began our previous chapter—what is soil? Soil is something of a very peculiar nature. It is a mixture of tiny mineral particles, organic matter derived from plant and animal remains, water with dissolved salts, air, and microscopic bacteria. All these are necessary parts of any soil which is capable of supporting plant growth. The mineral particles come from the weathering of rocks of the earth's crust. In weathering, the rock is broken down into smaller and smaller fragments, and at the same time is altered chemically. To make a good soil, the solid particles must be between certain limits of size; there must be not too much and not too little water, plenty of air, enough of the right kinds of mineral salts; the temperature must not vary beyond certain limits, at any rate during some part of the year; there must be a reserve store of organic matter, and enough of the right kind of soil bacteria to change this reserve capital into income available for crops, as well as other bacteria to obtain fresh income from the capital of nitrogen stored in the atmosphere. Soil is formed naturally over most of the land-surface of the earth. But man can increase the amount of it and improve its quality in various ways—by prevent-

ing it from being eroded away, by breaking it up and aerating it through cultivation, by altering its consistency and its acidity through adding lime and similar substances, by providing extra amounts of organic matter and mineral salts in manures and fertilisers, by encouraging the growth of the right kind of bacteria. Soil is unlike any other material found in nature, and its study is a science in itself.

CHAPTER VI

DEVELOPMENT AND THE STREAM OF LIFE

The Life-Story of an Animal—How a Chicken Develops—How Developing Animals are Looked After—Plants Develop as well as Animals—Other Ways of Development—The Stream of Life—The Life of Germs

THE LIFE-STORY OF AN ANIMAL

OUR bodies may in some ways be thought of as machines. But they differ a great deal from ordinary machines. For one thing, they can feel and think and plan, so they are something more than machines; they have minds, and an ordinary machine has not. For another thing, the way they come into existence is altogether different. With an ordinary machine the separate parts are all designed and made full size, then they are put together or assembled, and the machine is ready. But the living body-machine, in all animals and plants as well as ourselves, makes itself as it goes along.

It begins small and ends large. It begins simple and ends complicated. Its parts are not made separately and then assembled, but grow from the beginning in their proper places. They are not produced right away as finished articles, but shape themselves as they grow. We sum this up in a word by saying that animals and plants *develop*, and ordinary machines do not. The hen was once an egg; our fathers and mothers were once babies; the biggest oak was once an acorn. But a large locomotive was a large locomotive from the beginning.

As a beginning, we will look at the development of the

frog, which is very convenient to study, especially in the country, though in towns too it is easy to get some frog-spawn sent by post and keep it and see what happens to it. In late summer and early autumn you will sometimes see hundreds of tiny frogs hopping about in damp places near ponds or ditches. They are almost exactly like full-grown frogs, but will take about two years to grow up. A little earlier in the season, if you look in the water, you will find animals which are like tiny frogs, with long tails and no front legs. And if you take some of these and keep them in a dish with a little water in it, but tilted up so that part of the bottom is dry, you will find that after a time their front legs will burst through the skin, they will crawl out of the water, and their tails will begin to shrink until eventually there is no tail left, and they are simply froglets. So the tailless frog which lives most of its time on land and has no tail develops from a creature which lives in water and has a long tail to swim with.

In this state it is called a tadpole. In the spring, the tadpole, then a little creature less than a quarter of an inch long, was hatched out of a transparent sphere of jelly, about the size of a boiled tapioca grain; and this jelly was the covering of one of the hundreds of eggs laid by the mother frog. This covering protects the egg; as it is very tough and slippery it makes it difficult for animals to get at the egg inside and eat it. Some eggs,

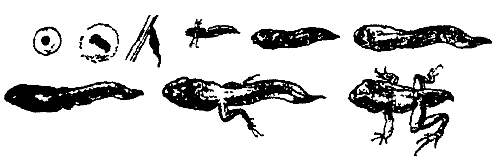


FIG. 109.—*How a frog develops. The egg turns into an embryo which hatches into a tadpole. The tadpole grows legs; finally its tail shrinks and it comes out on land as a little frog.*

like those of starfish, have only a tiny thin membrane round them when they are laid in the sea. But most eggs of backboned animals are well protected. Sometimes they have a hard shell, like a bird's egg; sometimes a leathery shell, like a lizard's or a snake's egg; sometimes a horny case, like a dog-fish's egg; sometimes only a jelly covering, like frogs' or newts' eggs.

The frog's egg itself is inside the jelly covering, and consists of a little round dark-coloured ball, about two millimetres in diameter, which is about the size of a No. 5 shot. So, in the frog's development there are the following stages: First, the mother frog lays the eggs. The eggs are not in the least like a frog or indeed like any grown-up animal. But in the next stage, while the eggs are still inside their covering, they change so as to turn into a little creature which can look after itself. This little creature is the young tadpole. It hatches out of the transparent egg-case, and then proceeds to grow, which it could not do before, as it could not eat while it was inside the egg-case, but had to live on food-substances, which are rather like those which make up the yolk of a hen's egg, stored inside the egg. While the tadpole grows, it changes slowly. At first it has feathery gills on the side of its head, but later these are grown over by a protecting flap rather like a fish's gill-cover (see Fig. 109). When it hatches it has no trace of legs, but after a time tiny buds appear in the right place and slowly grow into stumps with finger-buds on them, and then into properly formed legs. Finally, when the tadpole is well over an inch long, its body changes its colour and shape to look like a frog's, its fore-limbs burst out from under the gill-cover, and its tail and gills begin to shrink. At last they shrivel right up and are absorbed into the body, and the little animal, being no longer able to

breathe under water, comes out on land, where it can use its limbs and breathe air with the lungs that meanwhile have grown inside its body. After this, its development consists almost entirely in growth: it takes two or three years for the froglet to become a full-sized frog: and then it can lay eggs and begin the cycle all over again. Until this stage development has been upwards. But eventually downhill development sets in. Even if the frog escapes its enemies, it grows old and finally has to die.

So the development of an animal like a frog consists of an upward part and a downward part. During the upward part two kinds of processes are at work. One is growth, which means an increase in the amount of living matter in the developing animal. The other is what is called differentiation, which means that fresh differences keep on appearing between the various parts of the animal, so that it grows more and more complicated. At one time, differentiation is very rapid, and the fish-like, water-breathing, swimming tadpole turns into the air-breathing hopping frog, leaving the water for the land. Such thorough-going changes are common in the development of higher animals: we shall see another example later, in the butterfly. The downward part of development consists in a gradual wearing out of the body machinery, which results in the symptoms of old age, until finally, for one reason or another, the machinery no longer works, and the animal dies.

How a Chicken Develops

Development in most higher animals and plants shows the same general features. Let us first compare the developing frog with a developing fowl.

A bird's egg is of course far bigger than a frog's; but it is much better protected and looked after, and so the

bird need only lay a few, instead of hundreds. Domestic fowls may lay a couple of hundred eggs in a year, but this is only because of the treatment they receive. In nature, after they had laid eight or ten, they would get broody and sit, and then look after the chicks when they hatched out, instead of laying eggs all the year round.

The hen's egg has a hard shell which protects it. Inside the shell most of the egg consists of stores of food on which the developing chick can live till it hatches out. This food is in two parts, the white or albumen (which is only white when boiled; in the living egg it is a transparent thin jelly), and the yellow yolk.

The yolk develops in the hen's ovary. (Ovary means egg-producing organ.) If a hen is killed and dissected, it is easy to see the ovary with yolks of all sizes growing in it. When the yolk grows to a certain size, it bursts out of the

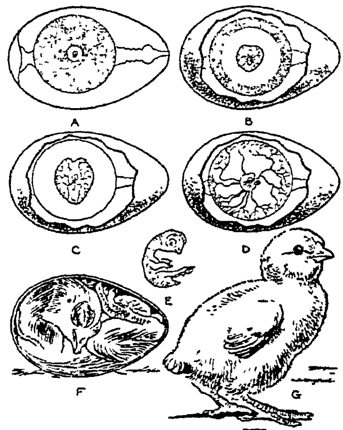


FIG. 110.—*How a chick develops. A. Diagram of an egg after being brooded* 12 *hours. The yolk (dotted) is slung in the white by two tough strands. B. The embryo is just visible after* 24 *hours' brooding. The embryo is bigger, and bloodvessels have grown out from it. C. After* 2 *days; the head and eye are seen. D. After* 4 *days; the embryo is growing limbs. E. A* 10-*day embryo; the dots are the beginnings of the feathers. F. A* 21-*day embryo just ready to hatch. The knob on the beak is to break the shell. The feathers are all wet. G. A newly-hatched chick after its feathers have dried.*

ovary and passes down a tube called the oviduct, which means egg-tube, to be laid. But while it is passing along this tube, glands in the first part of the oviduct pour out albumen round the yolk, and other glands in the lower part build the shell, which is made of lime. Sometimes fowls lay eggs with weak shells. This means that they are not getting enough lime with their food; then the poultry farmer gives them crushed-up oyster-shells, or something else with lime in it. In some birds a third set of glands

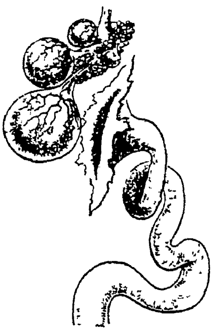


FIG. 111.—*A hen's ovary and oviduct. The egg-yolks develop in the ovary. When they are of full size, they break out of the ovary and pass into the mouth of the oviduct. The whites and the shells are put on as the yolks travel down the oviduct.*

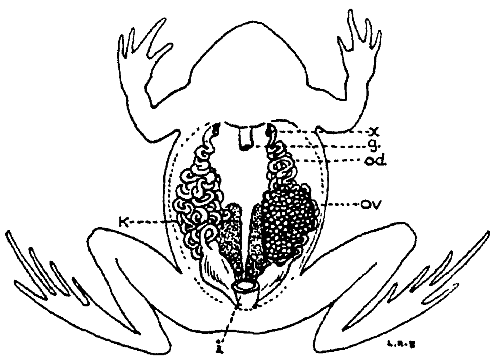


FIG. 112.—*A frog's ovaries* (*ov*), *and oviducts* (*od*), *as seen when the stomach and intestines have been cut away. k, kidney; g, cut end of gullet; i, cut end of intestine; x, opening by which the eggs pass into the oviduct after breaking free from the ovary.*

in the oviduct squirt out coloured material on to the shell, and this gives the egg its markings, which are often very beautiful.

As a matter of fact, the same sort of thing happens in a frog. There is an ovary and an oviduct; living eggs grow

in the ovary, burst out of it when ripe, pass into the oviduct, and have jelly poured out round them by the glands in the oviduct, to make coverings for them. In a dissected female frog the ovaries and oviducts can readily be seen by pushing the intestine to one side.

Thus it looks as if the real egg of the fowl was the yellow part. This is actually the case. The yellow part is an egg which has been packed full of stores of the food-material that we call yolk, until it is over a thousand times as big as the egg of a frog. What people usually call the hen's egg is the white and the shell, together with the real egg, which is generally called the yolk because it is mostly made of yolk-material.

The living part of the hen's egg is a little patch of transparent substance on the top of the yolk. If you buy a setting of eggs and either put them under a broody hen or in an incubator, development will go on inside them. You can study this by opening eggs at different intervals and looking at what is happening inside. At first the intervals will have to be much more frequent, as the changes are much quicker then.

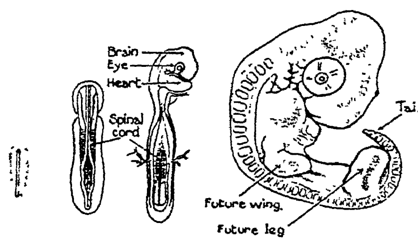


Fig. 113.—*The developing chick, magnified. Left, the first beginning of the embryo. Next, a 24-hour embryo, showing the spinal cord and beginning of the brain; next, a 2-day embryo; right, a 4-day embryo.*

During the first day, the little patch of living substance at the top grows very fast, and soon the beginnings of what we call the embryo can be clearly seen, as is shown in the pictures.

An embryo is a developing animal or plant inside an egg or a seed or inside its mother's body, before it is able to look after itself or lead an independent life. After about twenty-four hours the chief parts of the chick embryo which you can see are the future brain and spinal cord, and on either side of this little square blocks which will develop into muscles. A few hours later the heart can be clearly seen, and begins to beat. Meanwhile the living substance round the embryo has spread like a sheet a long way over the yolk. The heart pumps blood through blood-vessels which have grown in this sheet, and the blood picks up dissolved food out of the yolk and brings it back to supply the embryo, which needs material for its growth.

After two days of development, as you see in the pictures, the head has bent round, the beginnings of the eyes and ears are to be seen, and the body is much longer. Between the second and third days the whole body gets enclosed in a transparent bag containing liquid. This acts as a water-cushion and prevents the embryo from being damaged. After about three days the first traces of wings and legs appear in the form of little buds, and the tail begins to show. The embryo is still not a bit like a bird. But it quickly gets bigger; the limb-buds grow out and sprout toes; the beak appears; and at about ten days the first beginnings of feathers are seen. Long before this the sheet of living substance outside the embryo has grown all round the yolk, and is covered with a network of blood-vessels; these bring to the embryo food from the yolk and oxygen from the air which leaks in through the porous shell.

After this the main change is mere growth in size. What is left of the yolk is eventually grown right over by the body of the embryo, and when the chick pecks its way

out of the shell this serves as a store of food for some days while the chick is learning to find food for itself.

The whole development to hatching takes twenty-one days. It is interesting to make drawings of embryo chicks at intervals throughout this time, and to note down the days on which different organs, such as the eye, heart, limb-buds, tail, feathers, and so on, make their first appearance.

After hatching the chick has to grow a great deal, but in a few months it is full-sized and can itself begin laying eggs. Here again upward development consists of growth and differentiation. There is also a thorough-going change in the animal's way of life at the moment when it hatches out of its shell. Before that, it is living on the yolk and albumen that its mother stored up for it; it is breathing by means of bloodvessels outside its body, on the membrane underlying the shell; and it lives bathed in liquid inside its water-cushion, which acts as the embryo's own private pond while it is too delicate to stand being rubbed or knocked—if you look at a newly-hatched chick, you will see it is all wet. After it hatches it breathes and eats like any other land animal.

How Developing Animals are Looked After

The chief difference between the development of a frog and of a hen is that when the hen is an embryo it is better protected and has more food provided for it. Accordingly it can go on being an embryo till it is much bigger and more developed, and does not have to begin feeding for itself until much later. Even when it has hatched out it is looked after by the mother hen for some weeks, till it is really able to look after itself, while frogs take no interest in their eggs, and tadpoles never know their

mothers. Finally, as developing fowls are better protected and better looked after than developing frogs, there need not be so many of them, for fewer will die or be eaten before they grow up.

In these ways reptiles such as snakes and lizards and turtles are halfway between frogs and birds. They have big eggs with a large store of yolk and a white and a strong shell, but in almost all cases the mother does not sit on the eggs or even guard them, much less look after the baby animals after they hatch out. So you will find that a turtle lays more eggs than a bird but fewer than a frog.

There are some animals which provide even less for their developing children than frogs do. Starfishes, for instance, and sea-urchins and most kinds of jellyfish and sea-snails and sea-worms lay tiny eggs with hardly any yolk in them. This means that the embryo has hardly any store of food to live on while it develops, and so has to hatch out and find its own food at the earliest possible moment. Starfish eggs, for instance, hatch out after about twenty-four hours into tiny creatures that do not look a bit like grown-up starfish, but swim about with cilia (see "Simple Science," p. 26) near the surface of the sea, and feed on the microscopic plants—mostly diatoms—that grow there. And the same sort of thing is true for the other animals which lay eggs of this kind.

These tiny creatures are quite defenceless, and most of them are eaten by small shrimps and baby fishes. So if any are to develop into grown-up starfishes and snails and worms again, there must be enormous numbers of them. As a matter of fact, every female of the common sea-urchin lays about five million eggs every year—nearly as many eggs as there are people in London—and a single female of one particular kind of starfish lays forty million eggs at

a time! In spite of this, sea-urchins and starfish do not get more abundant year by year; so clearly, of all these millions of developing creatures, only a few can ever get safely through all the dangers of their early lives and grow up.

Just as there are some animals which do less for their young ones than a frog, so there are others which do more for them than a fowl. These are the animals called mammals, which include creatures like rabbits and cats and horses, as well as human beings. These do not lay eggs at all: the mother herself does everything for the embryo. Instead of developing inside a protecting shell, the embryo is protected by being inside its mother's body. Instead of having to provide the embryo with a store of reserve food-material all in a lump, as in a bird's egg, the mother can feed the embryo out of her own food day by day with the food-substances dissolved in her blood.

When the embryo is big enough, it is born. Even then the mother mammal goes on feeding it. Some birds, like thrushes and other song-birds, do this too, but they catch insects and grubs to give their young, while mammals feed their babies with a special nourishing food they make in their own bodies, namely milk. It is only when the young ones grow older that the mother stops feeding them and they have to eat ordinary food.

It is interesting, by the way, that there are some creatures which are half-way between mammals and reptiles. The duck-billed platypus is the best known of these. It feeds its babies with milk like other mammals, but it lays eggs with whites and shells and big yolks like a turtle or a snake.

There are other mammals which are half-way between the platypus and the mammals we know best, like dogs or

monkeys. These are the pouched mammals, like kangaroos and opossums. In these the arrangements for nourishing the embryo inside the mother's body are not so perfect, and the baby animal is born after a very short time. A new-born kangaroo, for instance, is only about an inch long. However, the mother has a special pouch on her body, like a pocket of skin, and the baby lives inside this for a long time, meanwhile feeding on its mother's milk.

In some birds, like the brush-turkeys, the chicks have

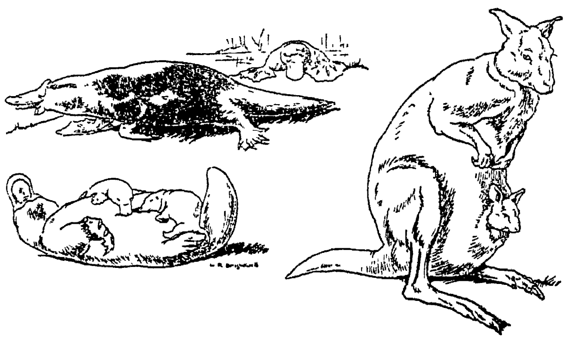


FIG. 114.—*How animals look after their young. The platypus lays eggs, but feeds its young on milk; the milk is squirted out on to a bare patch of skin which acts as a saucer. The kangaroo carries its baby in a pouch.*

to look after themselves from the moment they hatch. But in all mammals, even the platypus, the mother looks after her babies. With many mammals, the father also helps in taking care of the young ones (this happens in many birds too), and so the family grows up together. When this is so, the parents sometimes teach their children things about finding their food and avoiding their enemies. With most birds and mammals the young ones are ready to

leave their parents and live their own lives in a few weeks or months, though they stay longer with creatures like elephants, and with apes such as chimpanzees and gorillas. But it is with human beings that children are looked after and taught for the longest time. As this is so, they are better protected and are less likely to die while they are growing up. So while starfish produce millions and frogs thousands of eggs, and while birds lay one or two sets of eggs every year for years, and almost all mammals produce at least ten or twenty young ones during their lifetime, the average number of children in a human family is only three or four, and yet this is enough to keep up the numbers of the race.

So we see that while all animals are alike in having to develop, during their development some kinds are much better looked after than others; and the better they are looked after, the more they can learn and the better they are able to fit themselves for grown-up life before they have to look after themselves.

Plants Develop as well as Animals

So far we have only spoken about animals; but what about plants? Do they too develop in the same sort of way? It is quite easy to study this for yourself. Get some seeds—say beans, or grains of maize—soak them in water for a day, and then plant them in a wooden box in moist soil or sawdust. If you want to watch the growth of their roots, take a big jam-jar, make a hollow cylinder of blotting-paper inside it just up to the top, and fill the jar up with sawdust. Put the seeds in the narrow space between the blotting-paper and the glass, and then wet the sawdust thoroughly. You will be able to see what happens through the glass, instead of having

to pull the seedlings up by the roots. If you are using beans you will find that they swell a good deal after being put in water. This is because they have actually taken up a good deal of water into themselves.

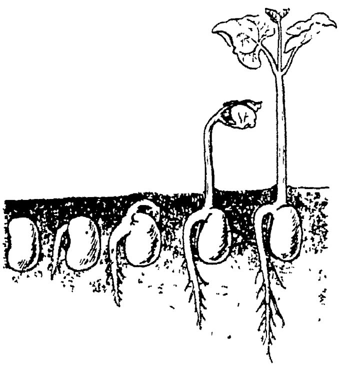


FIG. 115.—*How a seed develops. A bean seed planted in the soil sends out its root, then its shoot. The root branches and grows deeper, the shoot pushes up into the air and grows leaves on its stem.*

A day or so after planting the outer coat of the bean splits, and a little white pointed object comes out at the split. This is the beginning of the root. It bends over and grows steadily downwards. Soon tiny hairs appear near its tip, which are the root-hairs for absorbing food-materials, and a little later side-branches grow out from the main root. After the root has grown well down, the leaves and stem push out through the crack in the seed-coat. The stem grows upwards, and in a few days the leaves (there are two of them) have expanded nicely and become green, so that they can make food—sugar and starch—for the plant out of air and sunlight. The stem and the root go on growing, new side-roots and new leaves are budded out, and after some weeks or months the plant is old enough to flower and produce seeds itself.

However, this part of the plant's development only corresponds with the fowl's development after the chick has hatched. What happens before this? You will get some answer if you look at a bean before soaking and

planting it. Outside, the seed is surrounded by a tough coat. You can easily peel this off, and then you will find that most of what is left consists of two fleshy-looking white halves. If you gently force these apart, you will see that they are both joined by a thin stalk to a little object between them. This is the embryo plant. It has a miniature root at one end, and at the other a miniature stem with two tiny leaves. These are white because they are in the dark: they only become green after sprouting. The root and stem

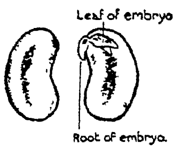


FIG. 116.—*Seeds contain baby plants. A bean seed split apart. It consists of two fleshy halves which contain food-material; between them is the embryo plant.*

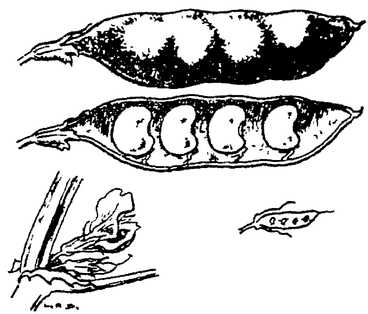


FIG. 117.—*The development of seeds and fruits. A bean-pod contains seeds which are attached to the wall of the pod. The pod grows out of the ovary of the bean-flower, and the seeds grow from the ovules in the ovary.*

are just waiting to grow out as soon as the coat splits. But what are the two fleshy halves? They too are really leaves. They are not doing the ordinary work of leaves, but are packed tight with reserve food-materials of various kinds. In fact, they do for the young plant just what the yolk does for the embryo chick—keep it going until it can manage to feed itself. After the young plant has grown for some time, these seed-leaves, as we may call

them, are quite shrivelled, because the food-stores have been sucked out of them. And if you carefully cut them off from a very young seedling, the plant will die, because it has no food. (Seed-leaves need not always be packed with reserve food. In some plants they are green and make food, but they always look different from ordinary leaves.) So the bean-seed consists of a coat surrounding a young plant waiting to be born. And the first two leaves of the young plant are used for storing food, not for making it.

If you want to trace the bean's development still further back, you must look inside a bean-pod while it is still green. You will find a row of partly-developed beans, each attached to the wall of the pod by a little stalk. Through the stalk they suck up food-materials from the mother-plant, and so can grow.

The pod itself was once the bottom part of a bean flower—what botanists call the ovary, as we saw in the last chapter. It then hadi nside it a number of little greenish bodies called ovules. As you can easily see by looking at a number of pods of different sizes, it is the ovules which gradually develop into the seeds that we call beans. While the future pod is still an ovary there is no trace of embryo plants in the ovules. The embryo plant gradually forms itself as the seed develops, just as the chick embryo forms itself on the surface of the yolk as the egg develops. So here again there is growth, there is differentiation, and there is a thoroughgoing change of life from the passive embryo to the active seedling plant.

There is one difference between this development and that of the frog or the chick, namely, that when the bean-seed is fully formed and falls out of the pod, it can stay for a long time without developing further, provided it is kept dry. It is in a resting or dormant state, only just

alive—less alive even than a hibernating hedgehog. This is very useful to us, for we can keep the beans and sow them when we want. But it is also very useful to the bean plant, for it means that the seeds can live for a long time in unfavourable conditions and yet will sprout if eventually they come into conditions which are favourable. Some seeds can live for several years. There are stories that "mummy wheat"—wheat-seeds that were buried with Egyptians who died several thousand years ago—has sprouted when it has been planted. But these are not true. No wheat-grains will sprout after more than about twenty years. Either the seeds found in the tombs had been brought in by accident, or else Egyptians who want to make money have cheated tourists by selling them ordinary wheat and pretending it came out of an old tomb.

Most seeds behave and develop like this. But not all plants have a dormant stage in their development, and not all animals are without one. For instance, sea-weeds have no seeds, but only tiny eggs; and most of them have no resting stage. Butterflies and moths are animals, but they do have something in the nature of a resting stage.

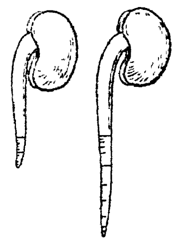


FIG. 118.—*The root of a bean seedling grows mainly near its tip.*

It is interesting to study the way in which the young plant grows. Take a bean seedling which has a root about one inch long, and with a fine pen and India ink mark off equal intervals along the root as shown in the picture. Intervals of one or two millimetres are convenient; you can mark them accurately with the aid of a ruler laid alongside the root.

Then hang the seedling in a closed jam-jar, covered to keep out the light, with water in the bottom to keep the air moist, and look at the root one day and two days later. You will find of course that it has grown; but you will also find that the marks are no longer the same distance apart, which means that some parts have grown much faster than others. As a matter of fact, the most rapid growth takes place just behind the tip of the root.

In another seedling you can do the same experiment with the stem. You will find the same sort of result, only the main region of growth is rather further from the tip, and is more spread out than in the root.

Growth can also be studied on bigger plants. A simple way of doing this is by means of a "growth-lever," as shown in the picture, which you can make for yourselves. The lever is a long light piece of wood which can turn about a pin near one end. The long arm of the lever should be a little heavier than the short arm, and opposite its tip you must arrange a wooden scale. On the end of the short arm you must tie a piece of cotton thread. Then take a potted plant, put some cotton-wool round its stem near the top, and tie the free end of the thread tightly round the cotton-wool. As the plant grows, the long arm of the lever will drop. If you measure the lengths of the two arms of the lever, you can calculate the amount of growth made by the stem which corresponds to each unit through

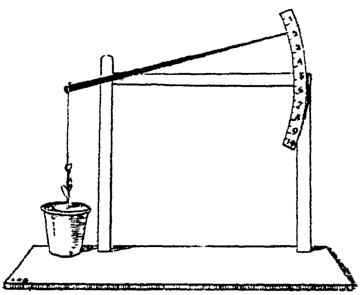


FIG. 119.—*Measuring the growth of a plant.*

which the lever's point drops on the scale, and so, by noting the position of the lever each day, you can make an accurate record of the plant's growth.

Other Ways of Development

The development of a butterfly or a moth is very interesting. The mother insect lays a number of small eggs, which are often very beautiful when looked at through a magnifying glass. Out of the eggs there hatch little worm-like creatures, the caterpillars, which at once

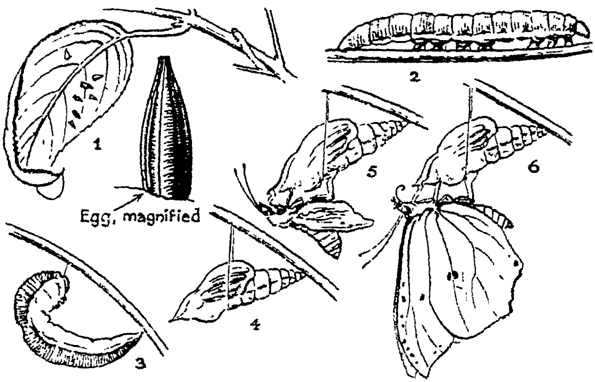


Fig. 120.—*How an insect develops. The life-history of the Brimstone butterfly:* (1) *Eggs,* (2) *caterpillar,* (3) *the caterpillar about to change into a chrysalis,* (4) *the chrysalis suspended by a silk thread,* (5) *the butterfly just emerged from the chrysalis,* (6) *the butterfly after its wings have dried and expanded.*

greedily set to eating, and grow very quickly. Finally, however, they lose their appetite, become sluggish, moult their skins, and turn into a quite different-looking object called a pupa, or chrysalis. The pupa cannot feed or see or move about. It is shut up in a rather hard shell, and

stays quite quiet, in some kinds of butterflies and moths only for a week or so, in others right through the winter. Eventually the hard skin cracks, and the perfect insect crawls out. Its wings are at first very small, but as the blood is pumped into them they soon expand and harden in the air, and the animal can fly away.

This kind of development is interesting in several ways. Inside the egg differentiation happens. A tiny embryo is formed (difficult to study even with a microscope) which hatches out as a caterpillar. The caterpillar, however, only grows and does not differentiate. Except in size, it is practically the same when full grown as it was when it hatched out of the egg. The pupa, on the other hand, does not grow at all, but a great deal of differentiation goes on inside its shell, so that the winged insect which comes out is altogether different from the crawling grub which went in. So the development of butterflies shows us not only that animals as well as plants can have a resting stage in their development, but that growth and differentiation, though both are needed in development, can go on quite separately from each other.

So far we have spoken only of development from seeds or eggs. But anyone who has had anything to do with gardens and gardening knows that this is not the only kind of development. A great number of plants are best grown not from seed, but from slips or cuttings. A little piece of the stem is taken, and planted in the soil. It grows roots from its bottom end and new leaves from its top end, and gradually develops into a full-sized plant. A familiar example of this is in potato plants. An ordinary potato that we eat is a piece of underground stem, swollen with starch and other nourishing material so as to act as a storehouse of reserve food. What people call

its "eyes" are little buds. To grow new potato plants, potatoes are chopped into little pieces, each with an "eye" on it, and the pieces are planted in the ground. The "eye" will begin to develop; it grows at the expense of the food-stores in the piece of potato, and soon sprouts up and turns into a young plant.

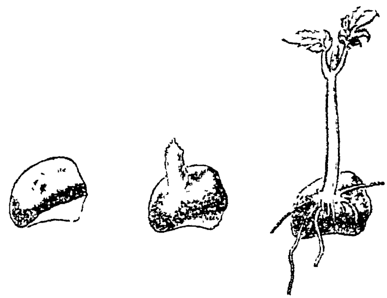


FIG. 121.—*Left, a piece of potato with a bud or "eye" in it. When planted in soil, after a few days a shoot grows out of the "eye" (centre), and later (right) roots also develop while growing. The young plant lives on the food stored in the piece of potato.*

Other plants are best reproduced by what is known as grafting. With roses, for instance, a little piece of the side of the stem with a bud on it is slipped into a cut on the stem of a growing rose plant: this kind of grafting is called budding or bud-grafting. The growing plant is called the stock, and the bit grafted on is called the graft or scion. Almost all kinds of cultivated apples and pears are grafted on to stocks. With these usually a whole piece of stem is cut off and used as the graft. It is fitted on to the cut end of a growing stem, and the two are tied tightly together. In either case the two pieces will join, and the graft, nourished by the roots of the stock, will sprout out and develop leaves and flowers and fruit.

It is interesting, by the way, that different varieties can be grafted together—for instance, a beautiful garden rose on to a wild briar. In such a case, the graft keeps its proper nature—the flowers of the garden rose are not smaller or

poorer because it is growing on a briar, nor is the fruit of a good-quality eating apple made sour by growing on a crab-apple stem. This is a very good example of the force of heredity, of which we spoke in "Simple Science," Part I, Chapter VII.

The fact that plants can grow in this way is very useful. Some cultivated fruits, for instance, have seeds that will not develop. Most bananas are like this; and there are even fruits, like the pipless orange, with no seeds at all. Then there are all the beautiful kinds of "double" flowers. Instead of stamens these have extra petals. Of course, as they have no stamens, they have no pollen to fertilize the ovules, and can never set seed. And other kinds of plants, like most sorts of cultivated apples and pears, will not breed "true to type"; if their seeds are sown, many or all of them will not grow up like their parents, but will develop into inferior kinds. The reason is a complicated one, to do with the science of heredity, and we need not bother about it here. In all these cases, if we want to reproduce that particular sort of plant, we can only do so by using grafts or cuttings.

Even in animals the same kind of thing may happen. We explained ("Simple Science," p. 274) how starfish could grow new arms and even parts of new bodies; and there are many animals which can be cut into several pieces, and each of the pieces will develop into a perfect animal. This is so with various small red fresh-water worms, with the little flatworms that are to be found in stagnant ditches, and with the hydra, which is rather like a tiny sea-anemone, only much thinner, which fixes itself to the stems and leaves of fresh-water plants. If you want to you can make experiments on these animals, and see the very wonderful process by which a little piece will

sprout out the parts that are missing and develop into a whole animal again, as is shown in the picture.

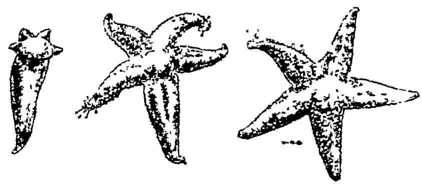


FIG. 122.—*A single starfish arm with a bit of the body growing into a whole new starfish.*

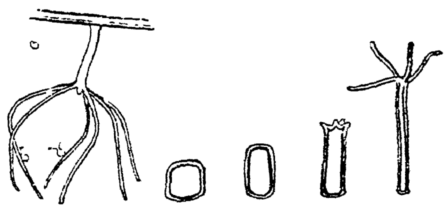


FIG. 123.—*Hydra, an animal which can grow missing parts. Left, a hydra hanging from a water-weed: it is catching water-fleas with its tentacles. Left (more highly magnified), a piece cut from the body of a hydra, and how it gradually turns into a complete animal.*

Of course in kinds of creatures which are made in a simple way, development too is very simple. This is so, for instance, in bacteria, including most disease-germs. When a bacterium has grown to a certain size, it simply splits in two. Each half grows to full size once more, and the process can be repeated over and over again. The same thing happens with animals like paramecium and other ciliates, even though these little animals are fairly complicated. These creatures multiply by dividing (Fig. 124).

THE STREAM OF LIFE

So far we have spoken of development from the point of view of the single animal or plant. We have found that the creature generally begins its career small in size and simple in construction, and has to get larger and more

complicated in order to become its fully-developed self. But there comes a point, as you trace development back, where the single creature or plant ceases to be itself any longer. Before this it was only part of another creature of the same sort. This is most easily seen in an animal-like paramecium. The whole body of one paramecium breaks into two, and each half turns into a new single animal, grows to full size, and repeats the process.

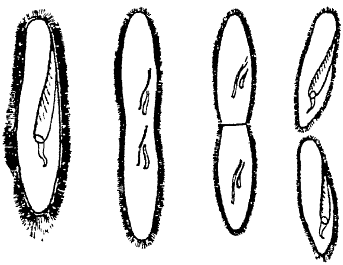


FIG. 124. — *How very simple animals reproduce themselves. Left, a full-sized paramecium. The little tube two-thirds way down is its gullet, which opens out of a shallow depression on its body. The animal becomes narrow in the centre, and finally splits into two half-sized animals.*

Just as water flows on in a river, so we may say that in any kind of animal life flows on in a stream. It is not quite the same as a stream of water, because the particular kind of living matter that makes parameciums, for instance, is broken up into a series of single animals. But each single animal was once part of its parent; and some time it, too, is going to break up to make its children. So there is really a stream of paramecium life.

Just the same is true with bacteria, or with a plant which is reproduced by cuttings. You can take a dozen cuttings off a single plant, and a dozen cuttings off each of these when they grow up, and so on. Each of the plants was once part of another; there is no real break between the single plants.

As a matter of fact, a continuous stream of living sub-

stance of this sort exists in every kind of animal or plant. The fowl was once a chick; the chick was once an embryo; the embryo was once a little patch on the yolk; and the yolk was once a part of the body of another fowl, an egg in its ovary. So with the moth, which was once a caterpillar, which grew out of an egg, which was detached from the mother moth's ovary, which in its turn grew out of her body as she developed.

There is, however, a difference between the moth or the chick on the one hand and the bacterium or the paramecium on the other. In the paramecium, *all* of the parent is converted into the children: one parent simply becomes two offspring. But in the fowl, only eggs can become fowls. All the rest of the bird, its feathers and brain and muscles and bones, its digestive tube and lungs and kidneys and the rest, can never develop into new birds, but must eventually die.

This means that the stream of fowl life flows in rather a different way from the stream of paramecium life. In each generation part of it flows out, so to speak, into a sort of backwater. This part makes most of the body of the single individual bird; it cannot be turned into new birds, and all of this part must finally die. But another and much smaller part makes the eggs in the ovary, and these have the power of turning themselves into new birds. The egg develops into bones and blood and brains and feathers and all the other things that make a hen, and also into new eggs; and it is only

FIG. 125.—*A diagram to show the stream of life. The hen's egg grows into the hen. In the hen is the ovary, which produces new eggs. The single hens die, but the stream of life continues through their ovaries and their eggs.*

these new eggs that can again develop. It is rather like having a stream flowing along past a number of ponds, so arranged that the water can flow from the stream into each pond, but not back again from the ponds into the stream. The ponds are like the bodies of the separate hens, the stream like the continuous stream of life through their eggs and their ovaries. We must suppose that after a time the ponds dry up, which would correspond with the death of the separate hens.

The fact that every kind of animal and plant is part of a continuous stream of life was only discovered in the last two centuries. It used to be supposed, for instance, that blowfly maggots were somehow produced directly out of decaying meat where they are formed. This supposed production of life out of dead matter was called "spontaneous generation." It was not until 1668 that a famous Italian scientist called Redi showed that this was not so. He made the very simple experiment—so simple that no one had thought of it before!—of putting out two pieces of meat, and then leaving one uncovered, but covering the other with gauze. After some days maggots appeared in the piece that was uncovered, but not in the other. The explanation of course was very simple. The gauze kept the mother flies away, and so no eggs could be laid on the meat underneath. Flies settled on the gauze, and even laid eggs on it; but when they hatched, the maggots died. So it was not the meat which bred the maggots: the maggots could only come from eggs, and the eggs could only come from other flies which in their turn had once been maggots.

It was fairly easy to show that animals as big as flies or worms always came from other animals like themselves. But when microscopic creatures were discovered, it was

much more difficult to prove that they were always part of a continuous stream of living substance, and could not be produced out of other kinds of matter. For instance, meat or broth or milk left exposed will putrefy, or "go bad," as it is often called. Everybody has always known this, but it was only in the last two hundred years that men discovered that, when anything putrefied, there were always bacteria to be found in it.

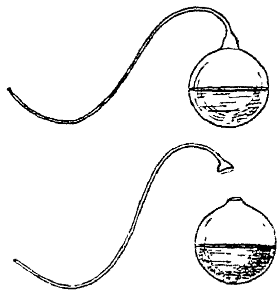


FIG. 126.—*One of Pasteur's experiments. A broth made from yeast was boiled in a swan-necked flask (above) and allowed to cool slowly. The broth did not go bad, because the bacteria spores in the air settled at the bottom of the bend in the neck. If the whole neck is broken off (below), spores can fall in, and the broth goes bad.*

At first it was supposed that the meat, or whatever it was, putrefied and decayed of its own accord, and that it somehow produced the bacteria in the process. After a time, however, it began to be suspected that things were really the other way round—that the meat would not putrefy of itself, but that it was made to decay by bacteria which had got into it. This was finally proved by Pasteur, the great French scientist, who worked in the middle of last century. He first showed that if a glass vessel with broth in it was thoroughly boiled, to kill any life there might be in it, and then sealed up while boiling, it would not decay, and there were no bacteria to be found in it; but if air was let in it went bad, and soon became cloudy through the growth of millions of bacteria in it. But the people who believed that the broth somehow bred the bacteria said that air was needed to help it and that

the broth did not putrefy because no air was let in. So Pasteur thought of two other experiments to test this. One was to take a glass vessel containing broth, boil the broth in it, and then in a flame draw out the neck of the vessel into a very thin tube with a deep bend in it. Then he let it cool very slowly, but without sealing up the neck. The broth was in contact with the air, but it did not putrefy, and no bacteria grew in it. This was because it is not the air which causes putrefaction, but the tiny spores or "seeds" of bacteria which float about in the air. As air was slowly sucked into the vessel while it cooled, these spores settled to the bottom of the bend in the neck of the flask, so that none of them ever reached the broth.

The other experiment was to take a vessel of broth, which had been boiled and then sealed up, to the top of a high mountain, break the neck of the vessel and let air in for a time, and then seal it up again. Even then no putrefaction took place. This was because there are no bacteria (or life of any kind) high up above the snow line, and so no spores could get in with the air.

The Life of Germs

These experiments of Pasteur's led on to other discoveries. For instance, when it was found that the spores of bacteria float about in the air, experiments were made to see how many there were in a given amount of air from different kinds of places. For this, little circular flat glass vessels with a lid are used, and are half filled, not with broth, but with a kind of jelly called agar-agar, made from a certain sort of sea-weed, on which most bacteria can grow. The jelly is poured in hot, and sets as it cools.

A number of these vessels are prepared and, after being

heated to make sure that no live bacteria are left in them, their lids are taken off for a definite time. If there are any bacteria spores about, some of them will settle on the jelly; and then each spore will hatch out and will multiply into thousands of bacteria. As they are growing on jelly they cannot move about, and so all the bacteria produced by one spore stay together, making what we call a single colony, and soon the colony is big enough to be seen by the naked eye as a whitish spot. So the more spores there are in the air, the more separate colonies there will be in the vessel. (Of course, in making the experiment there must be no wind or air-currents while the jelly is being exposed, or the results from different places could not be compared.)

By doing experiments of this sort, only with certain extra precautions, it has been found that the number of spores of bacteria in a cubic metre of air (a medium-sized room will contain over 50 cubic metres of air) varies enormously in different places. Over the ocean far from land, on high mountain peaks, and in the arctic regions, there are no bacteria at all. In the country a cubic metre of air will contain a few dozen. Out of doors in cities the same amount of air will often have several hundreds or even several thousands in it, while in crowded dirty rooms more than a hundred thousand bacteria may be floating about in each cubic metre.

Most of these spores in the air belong to quite harmless kinds of bacteria. But some of them belong to disease-producing kinds, and others can cause putrefaction not only in meat or broth but in living flesh if it is exposed in a cut or wound. So if a man has to be opened up for an operation there is a great danger of bacteria getting in from the air, and causing septic poisoning, which

simply means poisoning that leads to putrefaction. There are different kinds of septic poisoning according to the kind of bacteria which get in. In the old days a great many people who were operated on got poisoned in this way and many of them died; and the risk of poisoning was so great that big operations, such as opening up the body to deal with trouble in the intestines, were hardly ever attempted.

FIG. 127.—*A surgeon ready for an operation. He wears a mask, rubber gloves and overshoes, a cap and an apron, all of which have been sterilised.*

People were poisoned and died; but no one knew why. An English surgeon called Lister (he was afterwards made Lord Lister) thought a great deal about this, and when he heard of Pasteur's experiments he realised why so many patients were dying in this way. It was because bacteria got into their wounds, and poisoned their systems. So he began to try various methods for preventing this from happening at operations. At first he tried to kill any bacteria which might be present, by means of washing the wounds with antiseptics like carbolic acid (antiseptics are substances which kill harmful bacteria). But later he found that the best method was to try to have everything so clean that there would be no bacteria about to get into the wound. This is called the aseptic method, which means the "no putrefaction" method. To-day, when there is to be an operation the room, which is always kept very clean, is carefully disinfected beforehand. The patient's body, near where the cut is to be

made, is shaved and washed with antiseptic to kill any bacteria on his skin. All the instruments which are to be used are sterilised, which means that they are heated to a temperature which will kill any bacteria, the doctors and nurses have to wear white aprons and caps which have been sterilised in the same way, and finally the doctors who have to bend close over the patient wear masks to prevent them breathing or coughing or sneezing any bacteria into the wound.

FIG. 128.—*Sterilising surgical instruments. The instruments are arranged in layers in a container, which is then put in a steam-bath.*

As the result of these precautions, deaths due to infection by bacteria are now extremely rare after an operation, and operations that in the old days would have meant almost certain death from poisoning can now be safely done. And all this saving of human life is due in the first instance to Pasteur and the experiments which he did to show that bacteria, like other living things, come from other creatures like themselves, and cannot just be bred out of what they live on.

So this chapter, besides teaching us interesting things about the development of living things, and about the way in which separate animals and plants are always part of a continuous stream of life, shows that apparently quite useless things which science finds out may lead to results of the greatest use to us in our daily lives.

CHAPTER VII

THE IMPROVEMENT OF LIVING THINGS

Animals and Plants can Change—Heredity and Environment—Fertilisation and Genes—Heredity and the Recombination of Characters—Heredity and Evolution—The Deliberate Improvement of Living Creatures

Animals and Plants can Change

IN development, an animal or plant may pass through many stages, often very different from each other. If people had not actually seen a caterpillar turn into a butterfly, they would not believe that both were the same kind of animal. There are even stranger examples than this. An ordinary jelly-fish's eggs do not grow up straight away into new jelly-fish, but into polyps rather like little sea-anemones; and these bud off, from their top end, little saucer-like creatures which grow into jelly-fish. If you look where ferns are growing in a damp, warm greenhouse, you will see tiny flat green plants on the surface of the soil: these are another stage in the development of the fern. A fern has no seeds: the tiny spores that it forms on the brown patches on the underside of its leaves float away in the air when ripe, and if one falls on moist soil, it grows into this flat plantlet (which botanists call a prothallus). The prothallus forms eggs, and the eggs grow into new fern-plants (Fig. 130).

But in every case the stream of life repeats itself. In the fern stream of life the big fern-plant first produces a little prothallus, but eventually a new fern-plant of the same sort is formed again, not a moss-plant or even a fern of a differ-

ent kind. Duck eggs grow into ducks, not into chickens; white people produce white children, black people produce black children. Like begets like, as people say. This likeness of parents and offspring is what people usually call heredity.

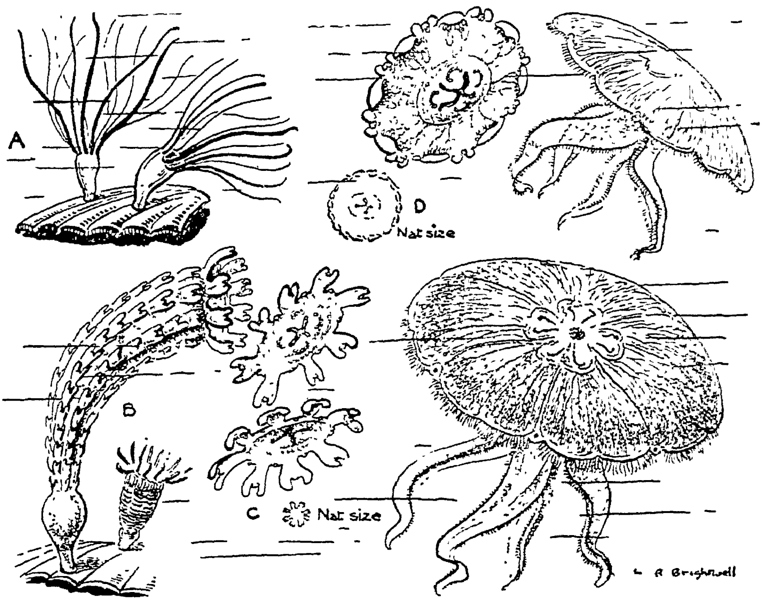


FIG. 129.—*The life-history of the jelly-fish Aurelia.* A, *the polyps which grow from the eggs* (*magnified*); B, *the polyps become divided up into tiny jelly-fish which become detached and swim away* (C), *these grow bigger* (D), *and finally turn into the full-sized jelly-fish* (*lower right*).

But heredity is not simply likeness. We all know that even in one family, two brothers or two sisters may be very different. One may be fair and the other dark, one clever and the other stupid, one strong and the other

weakly. So besides a general likeness, there is difference in detail—some degree of what is generally called variation. All kinds of living creatures show variation. No two sheep or flies or wheat-plants or human beings are exactly alike, and this applies to the offspring of the same parents as well as to the offspring of different parents. So it is clear that variation as well as resemblance comes into a study of heredity.

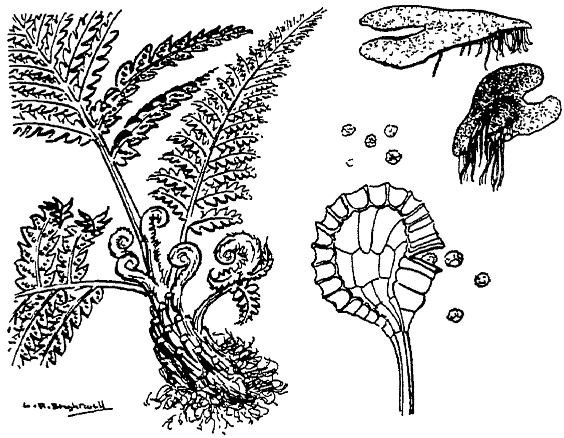


FIG. 130.—*The life-history of a fern. Left, the fern-plant, with groups of spore-cases on the under side of its leaves; lower right, a spore-case much magnified, bursting and discharging its spores; these grow into tiny flat green plants, the prothalli (upper right); and these produce new fern-plants.*

We also know that a particular kind of animal or plant need not stay unaltered over long stretches of time. We spoke in Chapter II of how the original ancestors of horses were very different from the horses of to-day, and the horse stream of life gradually changed during millions of years. However, there are other changes which are

much more rapid, and which we can often see going on under our noses. These are the changes in domesticated animals and cultivated plants.

Did you ever think, for instance, of the extraordinary variety of dogs? At one end there are Great Danes and mastiffs which weigh 11 stone and over—as much as a man; at the other, little toy terriers about one-thirtieth

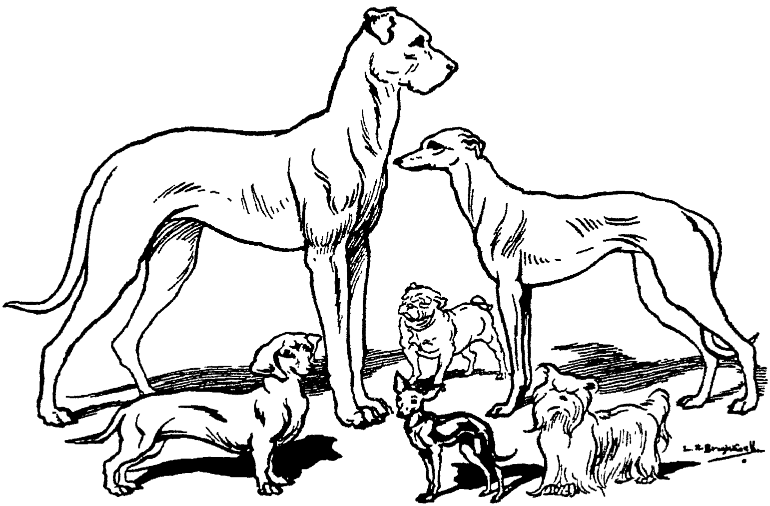


FIG. 131.—*Some of the breeds of dogs. Great Dane, Dachshund, Pug, Manchester Toy Terrier, Greyhound, Yorkshire Terrier.*

that weight. Skye-terriers can hardly see for hair, while there is a Mexican breed which is almost entirely hairless. Greyhounds are swift and slender, with pointed noses, while bulldogs are snub-nosed and built for strength. Dachshunds have short legs and long bodies, and were originally used for going into badger-holes; Borzoi have very long legs. And there are dozens of other breeds.

All these must have been brought into existence during the last few thousand years, for there is nothing like them among the wild dogs and wolves. They have been artificially created by man.

Similarly with horses. There are kinds of wild horses which have never been domesticated, and all our domestic horses must be descended from creatures like them. But some domestic breeds of horse, like big carthorses, are

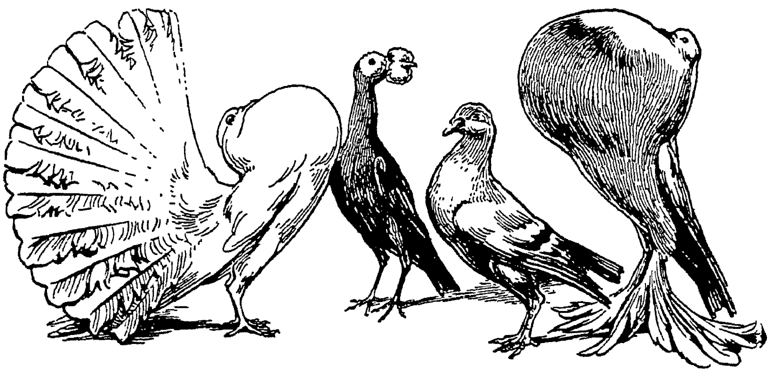


FIG. 132.—*Some of the breeds of domestic pigeons: Fantail, Trumpeter, and Pouter, with the wild Rock-dove (third from left) from which they are all descended.*

much bigger and slower than any wild horse; others, like Shetland ponies, are much smaller; and race-horses are swifter. Tame pigeons are all descended from the wild rock-dove that still nests round our coasts. Some domestic breeds, such as fantails, have more tail feathers than the wild doves; others, like the tumblers, cannot help turning head-over-heels at intervals as they fly; there are other breeds with queer shapes, like the pouter, or with strange wattles on their heads, like the trumpeter. To take

but one more example, fancy goldfish are all descended from a kind of carp which is still found wild, and is not gold at all, but olive-green in colour. Some of the fancy breeds have short tubby bodies very different from the

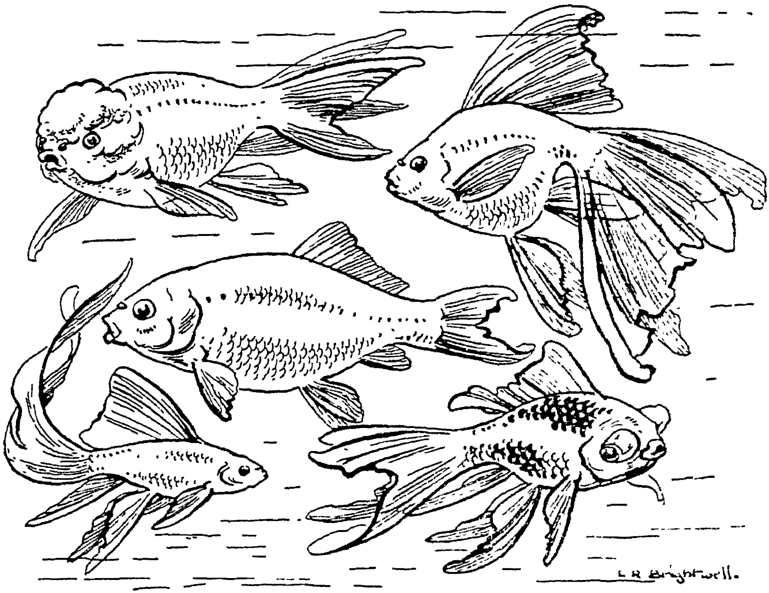


FIG. 133.—*Centre, the Common Goldfish, with some of the fancy breeds which have been produced from it: Left upper, Lionhead; left lower, Comet; right upper, Double-tailed Veil-tail; right lower, Double-tailed Telescope-eye.*

quite ordinary-looking body of the wild fish; some have goggle eyes on stalks, looking upwards instead of forwards; some have huge tails drooping like a train of filmy stuff; and some even have two tails instead of the usual allowance of one.

All these new and often strange types of animal have been produced by man. Sometimes we know that the change has not taken long. Most of the fancy goldfish breeds, for instance, have only come into existence during the last few centuries. Sometimes the change can be seen

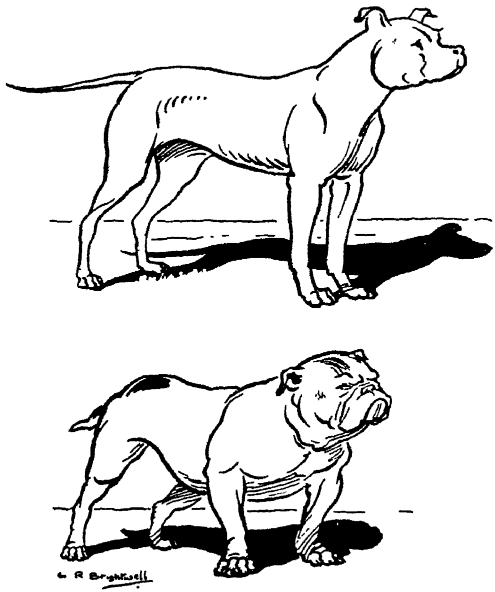


FIG. 134.—*A breed can change quite quickly. Above, a typical bulldog in* 1850; *below, a modern bulldog.*

going on under our noses. The prize bulldog of to-day is quite different from the bulldogs of less than a hundred years ago, which were used for bull-baiting: it is more snub-nosed, with jaws more underhung—altogether more of a fancy breed. Most of the change has taken place in the last forty or fifty years.

You can see just the same thing with plants. If you have ever eaten a crab-apple, you will know how different it tastes from an ordinary eating-apple: yet the crab is the ancestor of the orchard fruit. The wild carrot is a common

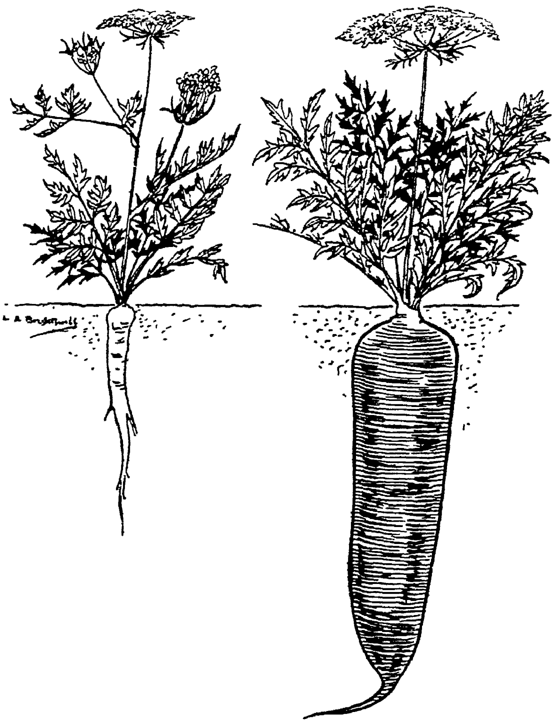


FIG. 135.—*A wild carrot (left), and a cultivated variety of carrot (right).*

plant: if you pull it up you will see it has only a thin woody root. Yet the carrot you eat has been developed from this by man. Similarly, cultivated wheat and oats and barley are the descendants of wild grasses. You will

see the effect that has been produced by man if you look at some wild oats and compare them with cultivated oats.

Garden flowers have been developed in the same way. Think of the varieties of snapdragons or carnations. There are plenty of wild roses, but none of them are "double," like the great majority of cultivated roses. When dahlias were introduced into Europe from their original home in Mexico, they were single, with a yellow centre and dull red rays. All the wonderful modern varieties, both of colour—whites, reds, yellows, and particoloured—and of shape, including the strange pompon and cactus types, have been developed from this original strain.

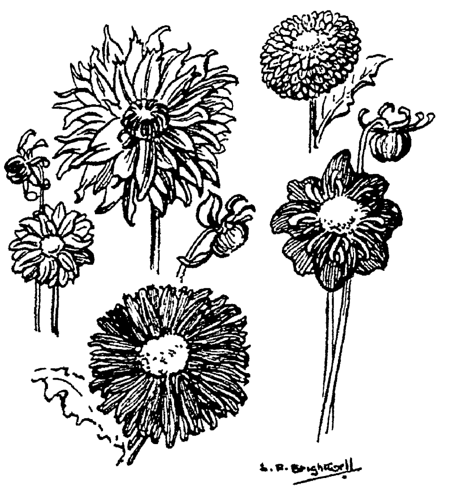


FIG. 136.—*The original type of dahlia (below), with some of the new varieties produced by man in a few centuries: left, Pigmy; above, Cactus; right upper, Pompon; right lower, Collaret.*

All these new kinds of animals and plants that man has somehow brought into existence will breed true to type. There has been gradual variation from the original type, and now the variation is fixed and part of the heredity of the new type.

Heredity and Environment

So you see that variation and heredity are entangled together. But we want to know more about them and their relation. The first and most important question to ask is whether all kinds of variations are inherited. If you think for a moment, you will see that this can hardly be the case. If you sow two portions of a single packet of seeds in two plots, and then leave the first plot untouched, while carefully weeding and watering and manuring the other, the two lots of plants will look very different—one will be small and stunted, with a poor seed-yield; the other will be big and luxuriant, with a good seed-yield. In other words, the plants from the one packet of seeds will show a marked variation. But if you then take seeds from the two lots, and grow them both in the same conditions, you will find that there is no difference in the plants that grow from them. Neither the variation in the direction of poor growth and poor yield, nor the variation in the direction of rich growth and good yield has been inherited (Fig. 137).

Or, again, children in England differ from children in France in speaking a different language. There is a very distinct variation. But if you were to take a French baby and bring it up surrounded by English people, it would speak English and would have just as much difficulty in learning French in school as we do.

The variation between the two lots of plants is produced by varying the conditions in which they develop. The variation between the two lots of children as regards their capacity to speak English or French is produced by varying what they learn naturally, and of course this is in a sense varying the conditions in which they develop.

A great many accurate experiments have been made

on this subject, and they show that variations of this sort, produced by varying the conditions in which animals and plants grow up, are not inherited.

On the other hand, if you take two packets of seeds, say of purple-flowered and pink-flowered sweet peas, the

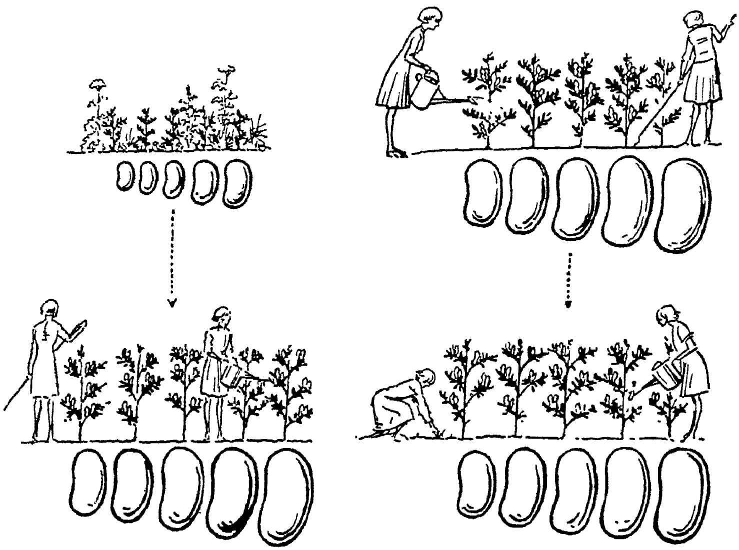


FIG. 137.—*Above, bean-plants grown in poor conditions (left) yield smaller beans than those grown in good conditions. But (below) if properly cultivated, the small beans will give just as good plants and seeds as the big beans. The effect of poor conditions is not inherited.*

plants which grow from them will be different even if they are grown in the same plot in identical conditions. Or again, children in England differ from children in Africa in the colour of their skins; but if you brought a negro baby to England, it would still grow up black.

This shows us one very important fact. Differences between two plants or animals or human beings are in some cases due to differences in the outer conditions, but in other cases due to differences in the nature of the plants or animals or human beings concerned. The cause of the difference may be either external or internal. Furthermore, differences which are caused by differences in external conditions are not inherited. But the differences, like those between black and white children, or purple and pink sweet peas, which show themselves even in the same external conditions, are inherited. We want a scientific name for the "nature" of the animal or plant which is inherited and which can differ in different varieties. It is usually called the genetic constitution (genetic is really another word for hereditary, derived from Greek instead of Latin). Similarly, all the external conditions in which an animal or plant grows up are usually called its environment.

In the previous chapter we saw that all living things develop: they usually develop from an egg, sometimes from a spore or a bud. So the egg (or spore or bud) must contain a definite genetic constitution. It also needs a certain kind of environment in which to develop. To take an obvious case, a frog's egg must have a watery environment, and would die in the air environment which is needed for a hen's egg.

What the animal or plant will eventually be like—its characters, as we generally say—depends partly on the nature of its constitution, partly on the nature of its environment during its growth. The seed of a green plant has a genetic constitution which in proper environment will allow the green colouring matter called chlorophyll to develop in the young plant. But

if you grow it in a dark cellar, the young plant stays white. On the other hand, plants like mushrooms and moulds are never able to develop chlorophyll, whether in light or darkness: they have a different kind of constitution. The actual green colouring matter in a leaf is a result of something in the constitution of the plant and at the same time of something (namely, light) in the environment outside it.

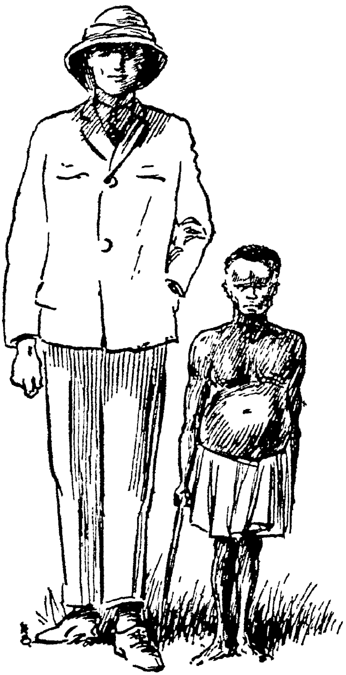


FIG. 138.—*A grown-up African pigmy by the side of a white man.*

This is true for every character of every animal or plant. Whether a human being shall be tall or short depends partly upon his constitution—nothing could be done to make an African pigmy baby grow as tall as an ordinary Englishman—and partly upon his environment—an English baby, if well fed, with plenty of vitamins and fresh air and exercise, will grow several inches taller than if underfed and brought up in a dark slum. To get a good wheat crop you need both good quality seed, and also good soil and manuring and cultivation. Some characters, like the shape of our heads or the fact that backboned animals have two eyes, seem to have much less to do with the environment. But even they can be altered.

For instance, if you put fishes' or frogs' eggs into certain salt solutions, they will develop with a single eye at the front of the head in place of the ordinary two at the sides.

So if we want to put our findings into the form of a general rule we must say that every character of an animal or plant is the result of an *interaction* between the genetic constitution and the environment. Alterations either in the constitution or in the environment can produce alterations in the character.

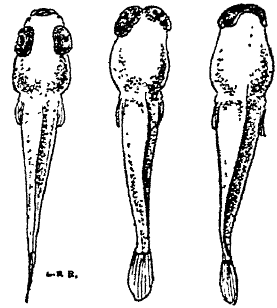


FIG. 139.—*Left, a normal top-minnow. Centre and right, two specimens grown from eggs kept in magnesium chloride; the head is small in front, and the eyes close together or actually joined.*

FERTILISATION AND GENES

Later we will come back to the results which can be got by altering the environment. Now let us deal with the question of genetic constitution. We shall find some interesting things about it and its behaviour.

The first thing which suggests itself is to cross two distinct varieties of an animal or plant and see what happens in later generations. A good example is a cross which was made between red-flowered and white-flowered varieties of an American plant called Four o'Clock (its Latin name is *Mirabilis*). All the seeds in the first generation grew up into pink-flowered plants. But when these were crossed with each other, only some of their offspring had pink flowers: others had red flowers and others white, just like their grandparents (Fig. 146, p. 274).

The first important thing to notice about this experiment is that the result was the same whichever way round

the cross was made, whether the red plant acted as the mother or the father.

In our last chapter we only spoke of the development of the individual from the egg, and of how the egg was once part of the mother's body. But there are fathers as well as mothers.

In "Simple Science," Part II, Chapter VI we explained that it was necessary, if a flower was to produce seeds, that pollen should reach the ovary. The ovules will not develop by themselves. What actually happens is not easy to see, because it happens inside the ovary of the flower, and also needs a good microscope. But botanists have shown that a pollen-tube grows down into an ovule, and there part of the living substance of the pollen-tube joins up with the living substance of a tiny egg (for plants have eggs as well as animals): this is called fertilisation.

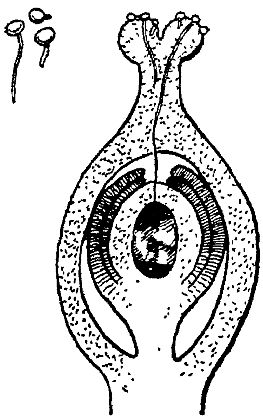


FIG. 140.—*A diagram of the inside of the ovary of a flower, showing a pollen-tube growing down into the ovule to fertilise the egg; somewhat magnified. Left, three pollen-grains more highly magnified, showing stages in the growth of the pollen-tube.*

In the same way, the egg of an animal will not develop by itself. It too must be fertilised. In animals, there is nothing like pollen or pollen-tubes: the fertilising is done by microscopic objects called *sperms*, which swim actively by lashing about with long tails like tiny whiplashes. The sperm is the male cell, the egg the female cell. Just as the eggs are produced by the mother, and were once part of her

body, so the sperms are produced by the father. If you look at a number of frogs in spring, you will see that some of them have dark horny pads on their wrists: these are the male frogs. If you kill one of these and dissect it, you will find the organs which produce the sperms in the shape of two oval white masses, called testes, near the kidney (Fig. 142). If you take a little bit of one of these, tease it up in a little water, and look at

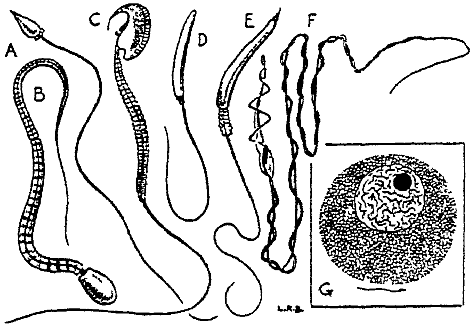


FIG. 141.—*Different kinds of sperms.* A, *sea-urchin;* B, *bat;* C, *field-mouse;* D, *frog;* E, *tortoise;* F, *greenfinch. All have a main "head" and a vibrating whiplash for a "tail," by means of which they swim to find an egg. Much magnified. Inset, a sea-urchin egg and sperm, both to the same scale. Magnified.*

a drop under the microscope, you will see hundreds of sperms swimming about.

If you want to see sperms being formed, an earthworm is the best animal to take. It has big white organs called seminal vesicles which act as storehouses for the developing sperms, and in a drop of fluid from these under the microscope you can see all stages in the growing out of their tails (Fig. 143).

If a sperm meets an egg, it will enter it, leaving its tail

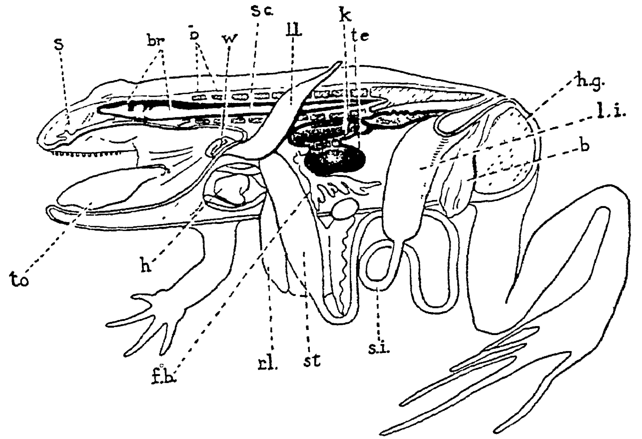


FIG 142.—*A male frog, dissected, from the left side, to show the position of the sperm-producing organs or testes* (te); s, *skull;* br, *brain;* b, *backbone;* w, *opening of windpipe;* s.c., *spinal cord;* l.l., *left lung;* k, *kidney;* h.g., *hip-girdle;* l.i., *large intestine;* b, *bladder;* s.i., *small intestine;* st, *stomach;* r.l., *right lung;* f.b., *fat-body;* h, *heart;* to, *tongue.*

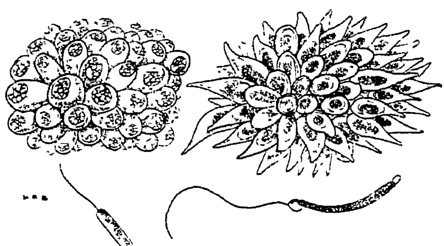


FIG. 143.—*The development of earthworm sperms. Above, left: a bunch of future sperms, still rounded like miniature eggs. Above, right: the free ends are growing out. Below, left: a single nearly-formed sperm; it has elongated and has produced a short tail. Below, right: a fully-formed sperm, much elongated and with a long tail with which it swims. Highly magnified.*

behind it, and unite with the egg. This is fertilisation, and the egg can then begin to develop.

There are a few animals and plants in which eggs can develop without being fertilised. Ordinary greenfly or aphis are the most familiar example. All the greenfly you

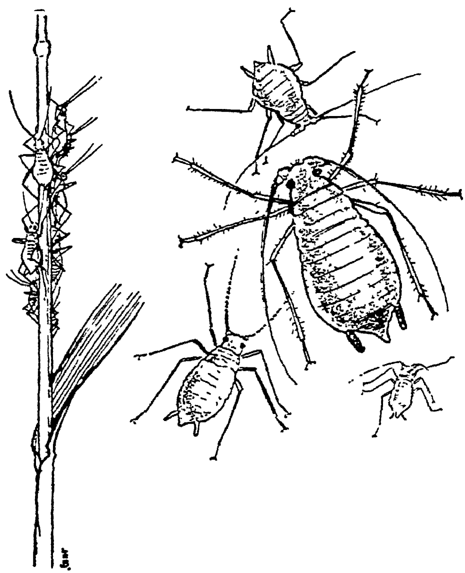


FIG. 144.—*Animals without fathers—greenfly (Aphis): left, a group of greenfly sucking sap from a plant. Right, greenfly of different ages, more highly magnified. All the greenfly you see during the summer months are females.*

see during the summer are female, and their eggs develop into new greenfly without needing to be fertilised by sperms, and so without having a father. Usually, however, two cells of different sexes must unite before there can be development. The male cell is always much smaller

than the female cell: it is either a sperm, or a part of the pollen-tube.

There is one further point to note about sex. In all familiar animals, the male cells and female cells are produced by different kinds of animals—male animals and female animals. This is so also with some plants; but with other plants—hazels, for instance—there are male flowers

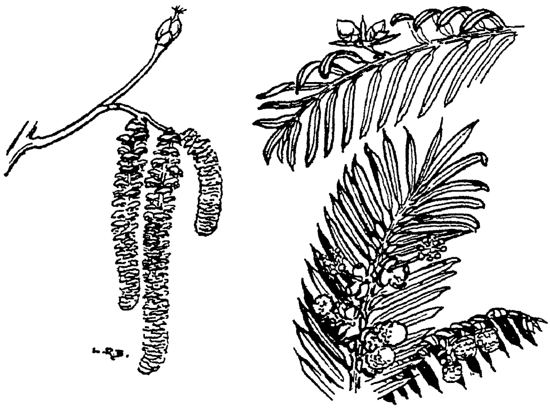


FIG. 145.—*Two plants with separate male and female flowers. Left, hazel, with a female flower above and three catkins of male flowers below. Right, yew: here the male flowers (below) and female flowers (above) are always borne on separate trees.*

and female flowers on the same plant; and in most familiar plants the same flower will produce both male and female cells. This production of male and female cells by the same individual also occurs in some animals, such as earthworms and snails.

Now we can go back to heredity. In our example of the Four o'Clocks, the flowers of the offspring were always the

same shade of pink whether the red-flowered parent was the father or the mother.

This is an example of a quite general rule—that, though the male cell is smaller than the female cell, sometimes very much smaller, it is just as important for heredity. The father and the mother contribute equally to the inherited constitution of the children.

But how can we account for the fact that the pink-flowered plants, which made up all the first generation of the cross, when crossed with each other produced in the next generation reds and whites as well as pinks? The simplest supposition is that both father and mother transmit to the offspring some definite particle of living matter which has to do with flower-colour, and that these particles separate again when the male or female cells are formed in the next generation. This supposition has now been proved to be true, and we call these particles *genes*. You cannot see genes any more than you can see atoms ("Simple Science," p. 594); they are too small. But we know they are there, because we can see their results.

The red-flowered plant then contributes a "red" gene (of course, it is not really red, but it saves time to call it the "red" gene instead of "the gene which causes the development of red flower-colour"), and the white-flowered parent a "white" gene. Let us call them *R* and *r* for short. Then the offspring all have one of each kind. During development, they exert a mixed effect, causing pink flower-colour. They themselves, however, do not mix, but stay quite distinct. And when the time comes to form new male or female reproduction cells, they separate, so that any pollen-grain or any egg will have either *R* or *r*, but never both (and never neither). There is an equal chance for either kind of pollen-grain to fertilise either

kind of egg. An *R* pollen-grain may fertilise an *R* egg—that gives *RR*—or it may fertilise an *r* egg, which gives *Rr*. Similarly an *r* pollen-grain can fertilise an *R* or an *r* egg, giving *Rr* or *rr* respectively.

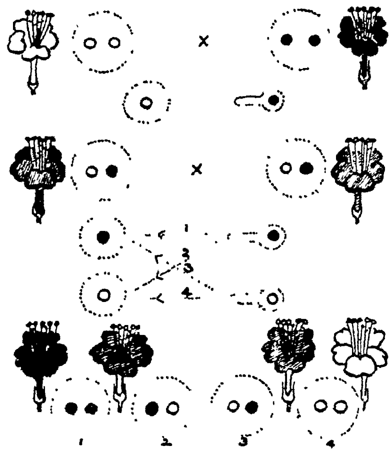


FIG. 146.—*A diagram of the heredity of flower-colour in Four o'Clocks. Top row, a white-flowered is crossed with a red-flowered plant; in the circles are represented the genes controlling flower-colour. Next row, an egg and a pollen-grain of the parent plants. Third row, the offspring are pink-flowered, and have one gene of each kind. Fourth row, when these are crossed they can produce two kinds of eggs and two kinds of pollen-grains, which can be combined in four possible ways. Bottom row, the result of these four unions:—one-quarter red-flowered, one-half pink-flowered, and one-quarter white-flowered.*

This means that of plants of the second generation, on the average one-quarter will have *RR*, one half *Rr*, and the remaining quarter *rr*. But a plant with two *R* genes will obviously have red flowers; one with two *r* genes, white flowers; and the *Rr*'s will have pink flowers.

A diagram will make it clearer.

Thus the genes do not mix, as drops of coloured ink might mix. They stay distinct, and their separations and meetings determine what the offspring shall inherit.

The genes are always in pairs, one from the mother and one from the father. When the two genes of a pair are different, they may have a mixed effect (even though

they do not mix themselves), as in our example from Four o'Clocks, where the red effect and the white effect were combined to give a pink effect. However, in other cases they may behave differently: the effect of one of the pair may be much more powerful, and

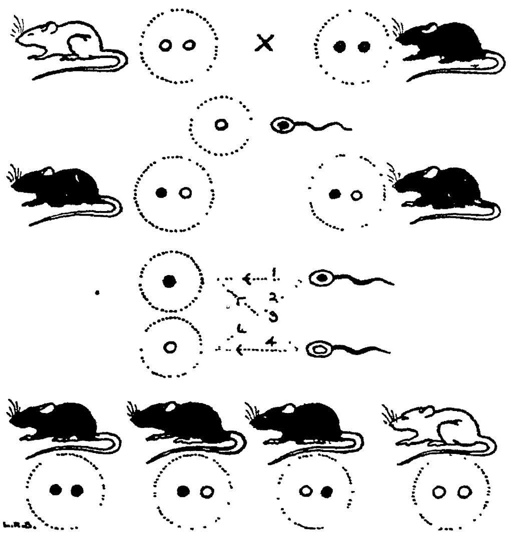


FIG. 147.—*After crossing a white (albino) mouse with a black mouse, all the offspring are black, because blackness is dominant over albinism. When these hybrid black mice are bred with each other, one-quarter of their offspring show the recessive character and are pure albino. The genes controlling coat-colour in the mice and in their eggs and sperms are indicated as in Fig.* 146.

hide the effect of the other. For instance, if you have pet mice you will find that crossing an albino mouse—that is one with white fur and pink eyes—with a coloured mouse—say black—will give you nothing but black

offspring.* We say the more powerful gene is dominant, the other recessive, because its effect recedes into the background. But the recessive albino gene itself has not disappeared. If you mate these black mice together, some of their children (a quarter, on the average) will be albino like their grandparent. The diagram will show that the case is exactly like the Four o'Clocks except for the dominance of the gene for black over that for white.

This is important because it shows us that we cannot tell the genetic constitution of an animal or plant by looking at it: the only way to find out is to make breeding tests and find out what kind of offspring it is capable of producing. The black mice with albino parents looked exactly like the black mice of the pure black strain: but they were capable of producing albino children while the pure blacks were not.

This explains the way things sometimes happen in human families. For instance, two ordinary people may have an albino child. Both of them must have been carrying an "albino" gene, but this was masked by the effect of its partner gene which gave ordinary coloured hair and eyes.

Heredity and the Recombination of Characters

The next question to ask is this—what happens when the parents differ in several characters, not merely in one? An experiment with garden peas will serve as an illustration. This example has a further interest, because it was one of the experiments carried out by the Abbé Mendel at Brunn, in what is now Czecho-Slovakia, in the middle of last century. These experiments of Mendel

* As a matter of fact this will not always be so. You must have albino mice of a certain strain. But in every case the offspring will be all coloured if the black parent is of a pure black strain, and there will be no albinos.

were very important, as they and the theories he based on them are the foundations for all our present knowledge about heredity. In fact the modern study of heredity is sometimes called Mendelism in his honour.

He had found that yellow and green colours in peas were inherited like colour and albinism in mice—one pair of genes was concerned, and the effect of one of the genes (that for yellow) was dominant. He also investigated the shape of the pea seeds. Peas are usually rounded and smooth, but in some strains they are wrinkled. This difference is due to another pair of genes, "round" being dominant to "wrinkled." The obvious question to ask was what happens if you put both pairs of characters into a cross—for instance, if you cross a plant from a variety which always has green and round peas in its pods with one from a variety with yellow and wrinkled seeds? Are the characters of the parents going to stick together in later generations—green and round, and yellow and wrinkled—or are we going to get all possible combinations of the characters, including new kinds of plants with green wrinkled seeds and others with yellow round seeds?

Let us try to work out what to expect. First let us have convenient symbols for the genes—Y for the gene producing yellow colour, y for the green-producing (it is simplest to stick to variations of the same letter for the two genes of a pair); R for the gene that makes the seeds round, and r for its opposite number that produces wrinkles.

Then the original plants were $yyRR$ and $YYrr$. Let us suppose that the pollen was taken from the first plant. Then all its pollen grains must have contained one y and one R—that is to say, yR—and all the eggs in the ovules of the other plant were Yr. When fertilisation took place, the two reproductive cells united: $yR+Yr=YyRr$.

Accordingly *YyRr* is the hereditary constitution of the offspring in the first generation. *Y* is dominant to *y*, so all the peas appear yellow; and *R* is dominant to *r*, so they all appear round. These characters, by the way, will already be shown by the peas in the pods of the original plants used as female parents, since the green and wrinkled characters are characters of the seed-leaves (Chapter VI,

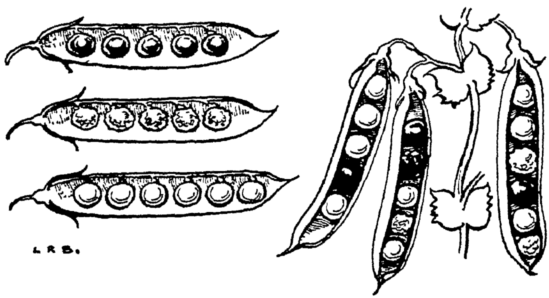


FIG. 148.—*Recombination. Left, top, a pod of a pea-plant which always produces green round seeds. Below this, a similar pod of a plant from another pure strain which produces yellow wrinkled seeds. Left, bottom, a pod from a plant produced by crossing these two strains: all the seeds are yellow and round. When two such hybrid plants are rossed, their offspring (right) have four different kinds of seeds—yellow round, yellow wrinkled, green round, and green wrinkled.*

p. 237), produced by the embryo as a result of fertilisation.

These peas then grow up into plants and produce flowers, and the flowers produce reproductive cells, male and female. In any one of the reproductive cells, only one member of each pair of genes will be found. So half the pollen-grains, for instance, will contain *Y*, and half *y*. Similarly, half will contain *R*, and the other half *r*. But the separation of *Y* from *y* has nothing to do with the

separation of *R* and *r*: the two processes are independent of each other. Accordingly, half the pollen-grains with *Y* will contain *R*, and half *r*; and the same will be true for those with *y*. In other words there will be four kinds of pollen-grains produced in equal numbers—*YR*, *Yr*, *yR* and *yr*. And exactly the same will be true for the eggs. What kind of pollen-grain shall meet with what kind of egg is a matter of chance—so each of the four kinds of pollen-grain has an equal chance of fertilising any one of the four kinds of eggs. You can easily calculate the result to be expected by using the same kind of system as for a tournament in which two sets of four teams are engaged, and where each team of one set has to play each team of the other set: this would mean that sixteen matches will have to be played. The pollen-grains and eggs are represented by the two sets of teams, and each match represents a possible fertilisation. Here is the scheme.

		Eggs			
		YR	*Yr*	*yR*	*yr*
Pollen	*R*				
	Yr				
	yR				
	yr				

You can fill up the sixteen possible results of fertilisation for yourselves, and then work out what the resultant peas will look like, and which of them will be true-breeding.

We need not trouble ourselves here about the average proportions in which the different types will be formed. The important thing to notice is that all the four kinds that are possible will actually be formed—green round and yellow wrinkled peas like the grandparents, yellow round peas like the parents, and an altogether new type in the shape of green wrinkled peas. Furthermore, some of each of these types will be able to breed true if crossed with others like themselves—namely, those in which both members of a pair of genes are alike. For instance, the *YYRR* peas will breed true for yellowness and roundness, unlike their parents of the first generation which looked the same, but were of different genetic constitution—*YyRr*.

Exactly the same kind of thing happens in other plants and in animals.

These facts at once bring us back to the question of variation with which we started. The green wrinkled (*yyrr*) peas are a new variation, different from their parents and grandparents. This variation has nothing to do with the conditions in which they are grown, but depends on a difference in their genetic constitution. On the other hand, it is not due to a change in the genes, but to a different combination of genes: there are no new genes, but the old genes are combined in a new way. Such variation we call recombination. We have only spoken of the recombination of two pairs of genes. But just the same thing happens with three or more pairs, except that then the new recombinations are much more numerous.

Accordingly, in genetics, two different processes are at work as regards the characters of parent and offspring.

One is inheritance, the other is recombination. One makes offspring like their parents, the other makes them different. Of course, in both cases, the genes are inherited, but the new combinations of genes produce quite new results. The kind of variation due to recombination explains why the children of one family may be very different from each other and from their parents in their characteristics and their genetic make-up.

These facts give us the fundamental laws of genetics—that the hereditary constitution consists of genes; that, before reproduction, the members of a pair of genes separate from each other in a clear-cut way and do not mix; and that the separation of the members of one pair of genes is independent of the separation of other pairs. There are a great many genes in the hereditary constitution of man or any familiar animal or plant—certainly many hundreds, and perhaps as many as ten or twenty thousand.

There are some minor exceptions to these rules, and a great many complications when we come to actual practice. However, here we need not trouble about them. Perhaps one point ought to be mentioned—that some differences between individuals or varieties do not depend on differences in a single kind of gene, but in several kinds, all of which have the same general effect. This is often the case with differences in size, though not always. For instance, there is a dwarf variety of pea that differs from the usual tall varieties only in a single gene. If you cross tall and dwarf, all the first generation is tall (because tallness is dominant), but if you cross these plants again, in the second generation you will get both tall and dwarf plants, with none of 'intermediate' size.

However, in poultry the difference in size between a

big breed like a Hamburg and a miniature variety like a Bantam is due to differences, not in one, but in several pairs of genes, probably four. Each of these genes makes a small difference in size. If you make a cross between the two breeds, the first generation is about intermediate, but when these are bred together, they give a range of size all the way from very small to very big, without a sharp break as with the peas. If you think, you will see why this is so.

Heredity and Evolution

Finally, there is one other kind of variation to be considered. Sometimes, even in pure-bred stocks of animals or plants, where there has been no crossing with other stocks for many generations, a new variety will suddenly crop up, and will breed true. For instance, the wild fruit-fly has dark red eyes. A variety with white eyes cropped up, and from this a pure white-eyed strain was easily established. Breeding tests showed that the new variety differed from the original stock in one gene only. What had happened was that in one fly, this gene had altered so that it now made the eye white instead of red. Once it had altered, the gene went on in its new state. Such a variation by alteration of part of the genetic constitution is called a mutation.

A very good example of mutation is found in the pretty little love-birds or budgerigars, which are often kept for pets. These have only been bred in captivity since about 1830. Originally, all the captive stock were green like the wild birds; but now blue, lilac, olive, yellow and other pure strains can be had. All these varieties are due to various recombinations of five pairs of genes; and all the five mutations involved have appeared since 1872. In

other words, during the last sixty years or so, five different genes have mutated into new forms among the budgerigars kept in captivity.

Mutations are rare, but they are going on all the time in nature. It has been found possible to produce them much more frequently by artificial methods such as X-rays; but what causes them in wild animals and plants is not yet known.

It used to be imagined that mutations always caused big or striking effects, like the change from red to white

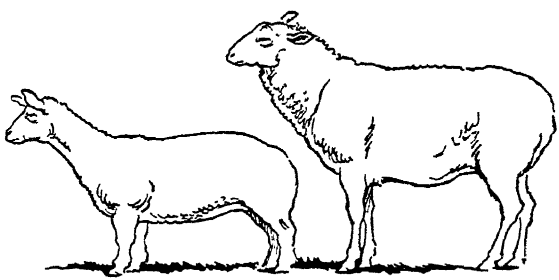


FIG. 149.—*A mutation. The Ancon breed of sheep with short legs (left) arose suddenly from a breed with long legs like those of the sheep on the right.*

eyes in fruit flies, or the change from long to short legs in sheep, which led to the so-called Ancon breed. However, we now know that variations due to mutation may be very slight as well as very striking: a gene may change a little, or moderately, or a great deal, in its nature and its effects. Mutations, in fact, may be of any magnitude.

Now we can go back to the question with which we began this chapter—the question of gradual change in

living things. In breeding new kinds of plants, one of the commonest methods is to use recombination. The plant-breeder takes different varieties, each with certain desirable characters, but also with certain disadvantages, crosses them, crosses their offspring again, and out of the many varieties which result, chooses those recombinations which have as many as possible of the good and as few as possible of the bad qualities.

For instance, a very common disease of wheat is rust. This is caused by a little fungus which feeds on the wheat plant. Some varieties of plants are naturally resistant to the disease—there is something in their hereditary constitution which prevents the rust fungus from getting a hold on the plant. However, none of these strains were satisfactory from the point of view of giving a high production of seed. So Sir Rowland Biffen at Cambridge crossed a rust-resisting variety with a high-cropping variety. Resistance to rust depends on a single gene, and is recessive. So all the offspring were susceptible to rust disease. However, in later generations all possible recombinations occurred, including some which had the genes for rust-resistance from one original parent, and the genes for good seed-production from the other, and from these a new improved variety was established.

Then there is the method of selection. Suppose you want to get high yields of seed from wheat. From a field of wheat you select the best ears and sow the seeds from these for next year's crop, and continue doing so year after year. For the first few years this will probably have quite a marked effect. This is because the original strain of wheat contained a number of different genes with an effect on seed-production, and gradually you are weeding out those for lower production. After a time, however, your

selection will have less effect. If you succeed in getting a really pure strain of wheat, selection would have no effect—unless a mutation took place in one of the genes concerned. If the mutation was one making for higher production, your selection would catch it, and gradually the old gene would be weeded out of the genetic constitution and the new gene left in, and your crop would again reach a higher level of yield. Selection without crossing is more used in animal breeding, especially where there are a number of pedigree breeds, as in cattle. It is by man's selecting the recombinations and mutations that happen to suit him, and rejecting the rest, that domesticated animals and plants have been caused to change their genetic constitution and so their very nature in the course of time.

With wild animals and plants, there is nobody to select or reject the variations that may crop up. All the same, selection of a sort is bound to happen. Some variations will give their possessors a slight extra advantage in their life, while others will put their possessors at a disadvantage in comparison with the rest of their kind. In every generation of every kind of animal and plant, a great many individuals die before they get a chance of reproducing their kind. A bird like a thrush or blackbird lives several years and lays several eggs every year, beginning before it is one year old. If we say it lives five years and lays four eggs once a year (both of which are probably under the mark) then a single pair will produce twenty eggs during its lifetime. If all these eggs developed and the birds from them grew up and again laid eggs, at the end of five years, when the old pair died, it would have left twenty children; the first four lots of these would already have had thirty-two grandchildren; and there would be large numbers of great- and great-great- and great-great-

great-grandchildren. You can work out the sum for yourself. This would mean that the numbers of blackbirds would be multiplied by quite a large figure every year. As a matter of fact we know quite well that the number of blackbirds in the country, apart from occasional ups and downs due to good or bad seasons, stays about the same. This means that the losses by death must balance

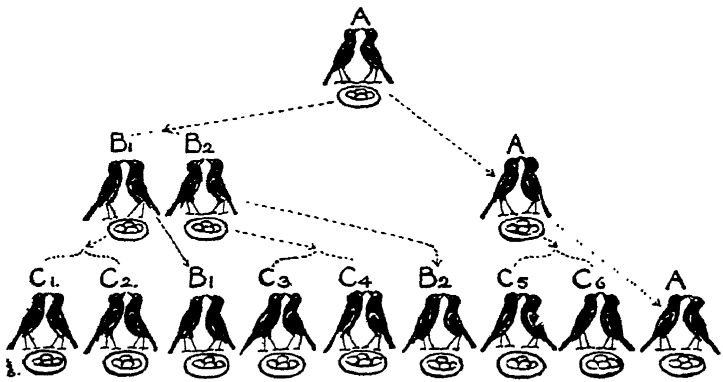


FIG. 150.—*What would happen if a pair of blackbirds nested for three years, laying four eggs each year, and all young birds grew up and nested. Top line, the original pair* (A) *with its* 4 *eggs. Middle line, the original pair and two pairs of its offspring* (B_1 *and* B_2). *Bottom line, the original pair has nested again, and so have two pairs* (C_5 *and* C_6) *from its last year's brood ;* B_1 *and their two pairs of young* (C_1 *and* C_2), *and* B_2 *and their two pairs of young* (C_3 *and* C_4) *have also nested, so that* 36 *eggs would be produced.*

the gains by reproduction, so that on the average each pair of grown-up blackbirds leaves only two descendants to grow up and reproduce their kind.

The same is true of plants, only here the number of offspring which never grow up must, in most cases, be much greater. Think of the number of acorns produced

by an oak-tree year after year, sometimes for several hundred years; and yet the number of oak-trees, apart from man's interference in planting them or cutting them down, stays about the same. A struggle for existence and for reproduction is always going on, although it is of course not a deliberate, conscious struggle.

Any variation which helped the seed of a plant to reach good ground for germinating, or made it grow faster when young, when it was competing for light and air with thousands of other seedlings, or made the plant more resistant to disease, or caused it to produce more seeds, would on the whole be an advantage in the struggle, and so on the average a larger proportion of the plants with this variation would survive and reproduce themselves than of the ordinary run of the plants or of plants with rather unfavourable variations. So here, too, there is a kind of selection. The survivors are selected in accordance with their ability to live and compete with other plants of the same kind in natural conditions. This idea was first put forward by the great naturalist, Charles Darwin: he called this kind of selection Natural Selection, as opposed to the Artificial Selection which man practises on his domestic animals and plants.

What happens as a result of Natural Selection is sometimes called "the survival of the fittest." But it is important to remember that when we say fittest, we only mean fittest in certain particular conditions. Think of a plant living in swampy surroundings in a moist region. If a mutation happened which made it able to stand even wetter conditions, this might easily be an advantage. But a mutation enabling it to resist drought would be useless, though it might be a great advantage to a plant living on the edge of a desert region.

A very good example concerns white clover. If seed is taken from white clover growing on an old grass pasture which is grazed over by animals, it will yield mostly creeping plants; but if it is taken from clover grown for some generations on clean land for seed, it will yield mostly erect, tall plants. The reason is that where there is grass, and where all plants are kept low by grazing, the creeping habit helps the clover to compete with the grass; and so creeping clover plants have an advantage over erect ones. But when it is grown for seed, the reaping machine artificially selects the upstanding seed-heads. So in one case selection acts in one direction, in the other in another direction, according to the conditions.

This idea of Charles Darwin's made it possible to understand how animals and plants gradually change in the course of time, and how it is that they are fitted to their surroundings, often in a very wonderful way. All the variations that make them less fitted to their surroundings are weeded out, those that make them more fitted are selected and kept in the genetic constitution. In wild animals and plants, recombinations have been, it seems, much less important than mutations. Most change in the hereditary constitution has come about through the selection of favourable mutations, which through the ages are gradually accumulated. But the study of the changes in wild animals and plants and how and why they have come about, which is generally called Evolution, is an enormous subject. We have described a few of its results in Chapter II. However, it would need a whole book to begin to discuss it properly, and here we can do no more than make this brief further reference to it.

THE DELIBERATE IMPROVEMENT OF LIVING CREATURES

Now we can turn back to consider some more of the changes brought about by man. When a stockbreeder is building up a breed of cattle, he has to consider first of all what it is wanted for—for instance, if mainly for beef, or mainly for milk, or as a "dual purpose" breed for both. But he also has to consider the conditions in which it is to live. For example, there are many parts of the world where cattle are very important—such as tropical Africa—but where the breeds that have been built up in places

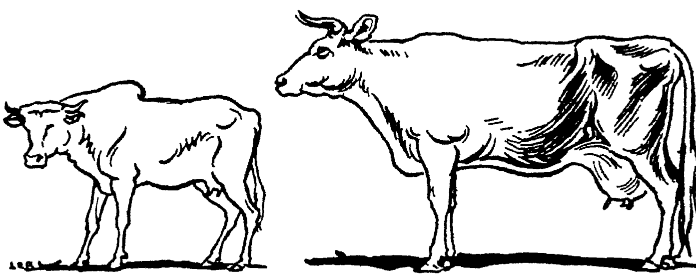


FIG. 151.—*A cow belonging to a native African tribe compared with a cow of a modern European dairy breed.*

like Western Europe turn out to be not much use. The reason is they are too good for the conditions of existence. Cows of a modern dairy breed have been selected to grow quickly, so as to reach the milk-giving age as soon as possible, and to give an enormous amount of milk. For instance, an Ayrshire cow becomes grown in two and a half to three years, and gives up to seven gallons of milk a day, while the cattle kept by the West African natives take eight to ten years to grow up, and never give more than one quarter the amount of milk. However, the Ayr-

shire cow lives in a moist country with plenty of rich pasture in the summer, and hay and cake are given to it in the winter. The West African country has much poorer soil. If you put Ayrshire cows in West Africa, most of the pastures there will not supply enough food for their rapid growth. Their body-machinery is working too fast, and is making too great a demand on the pasture. Their bones grow, but are not properly supplied with lime and phosphorus; in this and other ways they become unhealthy. Meanwhile the lower demands made by the slower growth and lower milk-yielding capacity of the native cattle are adjusted to well below what the poor pasture-lands can supply, and these animals can live healthily.

Of course, the native cattle could be improved: and, what is more important, the pastures could be improved by adding mineral fertilisers and in other ways—then they could stand up to the demands made by the better breeds of cattle.

Similarly with wheat. New breeds of wheat have been produced which can be grown in very dry regions where none of the older kind were of any use. This has been done by selecting for plants which made less demands on water. The yield is not quite so good as in some of the ordinary wheats, but by selecting for difficult conditions the total possible wheat crop of the world has been much increased. Unfortunately this scientific knowledge is not being fully used, because with the present system the farmers are not able to get a high enough price for their wheat (and other crops) when the crop is large, and so in many countries the amount of land where wheat and other crops are grown is being reduced instead of increased.

We will end this chapter with some examples from

grassland, which are interesting because they show the importance of different kinds of knowledge from different branches of science in making improvements. Grass is also important as being the most valuable single kind of crop in the world, since almost all farm animals live mainly on it. Our meat, milk, butter, leather, wool, and many other articles of less importance, like bone-meal, glue, and so on, are wholly or mainly the products of grassland.

The first interesting fact is that grazing alone will alter the character of pasture. Certain kinds of herbage stand up to grazing better than others. To take an obvious example, new trees will never grow where there are grazing animals, because all the young seedlings are eaten down. In parts of the New Forest there are fenced-in areas, and here you can see birches and pine-trees are growing up, while just outside the fence there are no trees. On a grass field, too, some kinds of grasses will survive grazing better than others. Then the dung of animals acts as manure; it makes the soil richer, and able to support more grass, and more luxuriantly-growing sorts of grasses. Experiments have been made in putting different numbers of sheep for different lengths of time on to rough, rushy pastures; and it has been found that grazing will by itself improve the pasture a great deal, making it more like a good meadow, with fewer rushes and more clover and soft grass. You can try such an experiment for yourselves on a small scale with rabbits or fowls.

In wet pastures, drainage will help too; and the addition of mineral fertilisers will in most cases make a great deal of further difference. The number of sheep or cattle which an acre of land can carry can often be doubled by adding fertilisers.

Finally, sowing the right kinds of grass may give a further improvement. Some very interesting experiments have been made at Aberystwyth on improving hill and mountain pastures. Most of these, from 800 feet upwards, are very poor. The soil is poor, and the climate is worse than at lower levels. In a natural state the land can only support rather wiry grasses which are not the best for grazing animals, and which die down early in the autumn. The hillsides in Wales or Scotland or northern England have an ashen look during the winter months,

FIG. 152.—*Right, the root of a leguminous plant with nodules on it. The nodules contain numbers of nitrogen-fixing bacteria (see p. 208). Left, different forms assumed by the nitrogen-fixing bacteria during their cycle of multiplication (much magnified).*

quite different from the valley pastures, which manage to stay green all through the year. This means that most of the sheep on the upland pastures must be sent down to the lowlands for the winter, as otherwise they would not find enough to eat.

The experiments just mentioned have shown that even such barren grazings can be thoroughly changed. First you must break up the soil, by ploughing or other means.

This gets rid of the old vegetation, and also aerates and drains the soil and so makes nitrate-production (p. 212) more active. Next you must add mineral fertilisers. And finally you must sow the right kinds of grass and clover seeds. The right kinds are varieties of lowland pasture plants which have been bred and selected to stand the difficult conditions of hill and mountain climate. You must also inoculate the clover seed with nitrogen-fixing bacteria (Chapter V, p. 208), for these are absent in the upland soils. When the plants come up, you must put sheep on the land. Their grazing and manuring, together with a very little fertiliser each year, will keep the pasture going. It will then continue as good grass and clover, which stays green all the year round.

About fifteen per cent. of the whole area of Great Britain consists of rough upland grazings which could be improved in this way, so you see how important the discovery of this method is. However, as with the improvement of wheat, this is not likely to have much effect until our buying and selling system has been improved so that sheep farmers could still get a fair return, even if they had double the number of sheep to sell.

We must not forget that the rules of genetics apply to human beings just as much as to plants and animals. Human beings, like other living things, differ from each other: they show a large amount of variation. As with animals and plants, part of this variation is due to differences in outer conditions, part to differences in hereditary constitution. You remember the saying in the Bible—you cannot grow figs from thistles. Similarly, you cannot expect to get good quality men and women out of inferior genetic constitutions. No amount of manuring will turn

thistles into figs, or improve the hereditary qualities of a poor strain of wheat. Similarly no amount of food will make the child of an African pigmy grow as big as an average Scot; no amount of education will make a naturally stupid baby grow into a clever boy or girl, for education will not improve people's capacity to profit by education—it will only allow their capacity to be properly exercised.

On the other hand you could not expect to get good figs unless you grew them properly: and in the last chapter we saw the need of right cultivation and sufficient manuring if the farmer was to expect good crops. So with human beings. You cannot expect to get the best results out of the constitutions which they inherit unless you provide the best possible conditions for them to grow up in.

There is a great deal of unnecessary ill-health and stupidity and suffering in the world to-day. A great deal is due to bad conditions of life; but some, we can be sure, is due to poor genetic constitution. There are some few cases where we can be sure that a defect or disease will be handed on by heredity to later generations. Some kinds of feeble-mindedness are like this, for instance, and a condition called hæmophilia or excessive bleeding, in which the blood will not clot properly and even a small cut or the drawing of a tooth may be dangerous. In cases like this it seems clear that people with such defects ought not to have children. Usually, however, it is difficult or impossible to be sure of most human characteristics what is due to heredity and what to environment. The first thing is to try to improve conditions of life—food, and housing, and education, and opportunities for interesting work, and recreation—in order to see what effect this will have. Only when this has been done we shall be able to

see more clearly what defects are due to genetic constitution.

But do not let us forget that if we chose to take as much trouble over improving the genetic constitution of the human race and the conditions of human life, as has been done towards improving crops and domestic animals, we could, in the course of one generation, secure just as striking results in human efficiency and happiness as the farmer and the stock-breeders have done with the yield and performance of their crops and domestic animals.

CHAPTER VIII

THE HISTORY OF SCIENCE

The Beginnings of Science—Science in Classical Greece and Rome—Science in the Dark and Middle Ages—The Beginnings of Modern Science—Eighteenth-Century Science—Nineteenth-Century Science

The Beginnings of Science

SCIENCE is the finding out of the rules about things and about the way they happen. It always has two sides to it. On the one side it gives us knowledge and understanding of what was previously unknown or mysterious or misunderstood; on the other side it increases our control over nature and the forces at work in nature. The knowledge gained by science affects our general ideas and our attitude to existence; the control made possible by science affects our everyday surroundings and the way we live.

In preceding chapters we have tried to give some notion of certain aspects of Science by showing the connection between scientific facts, and explaining some of the ideas derived from them and some of the practical applications that they have made possible. However, there is one very important scientific fact which we have hardly touched upon, and that is that science itself has a history, and grows and develops with time. Science is always incomplete: it will always be possible to know more than is known at any particular period. Science can never claim to be completely right: the accepted ideas of science are merely those best fitted to explain what is known at the time.

If we take a look at the history of science, we shall find that in the past there have been whole realms of nature about which there was no scientific knowledge. For instance, the bare facts about eggs and sperms, and the facts about electro-magnetism, were not known at all until the nineteenth century. We shall also find that the scientific ideas held at any one time were often wrong, and had later to be given up in favour of newer ideas. We must expect that in the future new realms, as yet untouched by science, will be explored by scientific method, and also that many of our present scientific ideas will have to be given up in favour of new ones. Science is not a fixed body of knowledge or a fixed set of ideas. It is man's way of accumulating tested knowledge about nature; it is constantly discovering more facts, and is constantly framing new ideas which are a little closer to the truth, to explain the facts. In this final chapter we shall try to give a further understanding of what science is and does by telling a little of its history.

Man has been in existence for several hundred thousand years. For all but a very small fraction of this long time, men lived what we should call a savage and primitive life. They subsisted by hunting wild animals and by gathering what food they could find ready-provided by nature, such as shellfish, roots, and various berries and fruits. They had a small but definite degree of control over nature. They knew the use of fire, and they knew how to make tools and weapons. These, however, were few and primitive, and were made of natural materials like stone, wood and bone; and their clothes were made of roughly prepared skins, or in warmer climates probably of aprons of leaves. They did not know how to prepare metals, or to grow crops, or to make a wheel, or to build in stone, or to weave or spin, or to write.

During all these tens of thousands of years, the chief progress that we know of was the very gradual improvement of man's stone tools—though doubtless a similar gradual improvement took place in implements of perishable materials and in his way of life in general.

Thus the first great human discoveries were the discovery of how to make and use fire, and how to improve natural objects like sticks and stones to serve as tools. We do not know when these discoveries were first made, save that it was several hundred thousand years ago. Much later, some tribes seem to have discovered how to tame certain wild animals—horses, cattle and dogs.

The next great discovery of which we have any definite knowledge was that of agriculture—deliberately sowing seeds and cultivating the soil in order to harvest the crop later. This happened somewhere in the Near East, either in Egypt or more probably in Mesopotamia, between six and eight thousand years ago. The discovery of agriculture was based on the scientific fact that seeds grow into plants. Men in the earliest ages either had not known this fact, or had not applied their knowledge.

Here we have a scientific fact, applied in practice, and completely changing men's way of life. People who practised agriculture could, for the first time in the history of the human race, amass large stores of reserve food. This meant that they could settle in one spot and build towns instead of always living scattered in small groups, often moving about from place to place in search of pasture for their herds, or of wild animals to hunt. It meant that some of them at least had more leisure and more opportunity for thought and study. As regards the history of science, we have to note an important fact, that the changed conditions of life brought about by this one

scientific discovery caused new needs to come into being, set men searching for the answers to them, and so led to new scientific discoveries. This sort of thing, we shall find, is always happening in scientific history.

If men were to grow good crops, it was important to sow the seed at the right time of year. For this, it was necessary to know the seasons accurately enough to construct a calendar. We are so used to having an accurate calendar of the year that we forget how much knowledge and skill have been needed for its making. Merely to have vague ideas about the seasons is not enough. The movements of the sun, stars and planets provide the only accurate measure of the recurring cycle of the year. So it came about that these early people began studying the heavenly bodies, and gradually obtained enough knowledge to make some sort of a calendar. Probably ancient temples like Stonehenge were observatories as well as places of worship. They seem to have been built so that when the sun rose in line with some opening in the circle of stones, the priests knew it was a special day, like Midsummer Day. All this, however, took time, and progress was slow. It was not until about 2000 B.C. that the Babylonians, who were the first great astronomers of the ancient world, finally fixed their calendar—and even then they made it 360 instead of 365 days, putting in an extra month from time to time to make it square with the real year, as we put in an extra day in leap years.

Eventually, however, a great many scientific rules about the behaviour of the sun and stars and planets were very accurately known in quite ancient times. But ancient astronomy was very different from that of to-day. The earth was thought to be flat, and the sky to be a sort of domed cover to it, not very far away, in which the sun and

stars travelled. The ideas that the earth was a round globe, or that it travelled round the sun, or that the stars were millions of millions of miles away in empty space, had not even been dreamt of.

When land became valuable for crops, it was also important to have accurate methods of measuring and surveying land: so we find in early civilisations that geometry (a word which is derived from Greek words meaning land-measuring) was much studied. There was no algebra until many centuries later.

This knowledge of astronomy and of geometry was the first really scientific knowledge gained by man. It gave people the idea of accuracy, and astronomical knowledge gave them the idea of order and regularity in nature. On the other hand, a great many facts of nature, like earthquakes and plagues, were still mysterious: people had found no scientific explanation for them. So for many centuries people lived with two main sets of rather contradictory ideas—the idea that there was order and regularity in some kinds of happenings, but not in others. Some parts of nature could be seen to obey rules, while other parts did not seem to happen according to any rule.

The loom, the art of writing, and wheeled vehicles seem to have been invented soon after the discovery of agriculture. But the next major scientific discovery was that of smelting and working metals, which occurred one or two thousand years later. Not only did metal-working make possible better tools and weapons, but it provided man with the first real coinage, so providing a stable basis for the exchange of goods and services.

Many improvements in detail of knowledge and practice and in general level of civilisation were made in the next two or three thousand years, notably in Mesopotamia,

Egypt, and Crete. Men learnt to build stone buildings, some of them of huge size, to make ships capable of navigating the seas, to work metals in all sorts of ways, to make glass. In metal-working, copper gave place to bronze, and bronze to iron. But no great scientific development took place until the classical age of ancient Greece.

Science in Classical Greece and Rome

In the Greek civilisation of the sixth century B.C. the basis was laid for the development of arithmetic, a map of the known world was made, and the idea that the earth was spherical was first put forward. In the fifth century the fact that air was a material substance and not just empty space was accepted, and the idea that matter was made of elementary particles or atoms was advanced. However, a typical view was that everything was made out of the four "elements"—earth, air, fire, and water; or as we should say, solid, gaseous, flame, and liquid—in different proportions.

The sun and moon were for the first time proclaimed to be made of the same kind of materials as the earth, and not bodies of some quite different nature. A good deal of anatomical dissection was practised to find out how the human body was made, and medicine began to be scientific. The study of development was begun by opening and examining hens' eggs at different stages.

The fourth century saw the rapid rise of the biological sciences. The great scientist and philosopher Aristotle made the first serious classification of animals and plants. In some respects this was very accurate; for instance he put whales and dolphins with land mammals instead of among fish. His writings are very important as being the first attempt at an encyclopædia of scientific knowledge.

The interest taken in natural knowledge at this time is seen in the fact that Alexander the Great took with him on his campaigns a staff of scientists to study geography and natural history.

The famous voyage of Hanno the Carthaginian down the West Coast of Africa was very important. He noticed that whereas in the first part of the voyage the mid-day sun stood in the south, later on, after being right overhead at noon, it stood in the north. This and other facts made it certain that the earth was really a sphere. About this time Euclid put together all that was known of the science of geometry in complete and logical form.

In the third century B.C. one Greek astronomer, by studying eclipses, showed that the sun must be much bigger than the earth, and gave a very good estimate of the circumference of the earth. The main centre of Greek culture had now moved to Alexandria in Egypt. Here a notable step was the foundation of the Museum, which means literally "the Home of the Muses." The Museum of Alexandria was not only a museum in our sense, but a university, with research departments and a huge library. After its destruction during the Dark Ages nothing like it grew up again until the scientific spirit came to animate the European universities in the seventeenth century.

Scientific medicine flourished during this period. One notable advance was the proof that the brain was the organ of mind, and not the heart, as even the great Aristotle had maintained. In this period lived the greatest physicist and inventor of antiquity—Archimedes. He discovered the important principle that when anything floats in a liquid, its weight is equal to that of the liquid which it displaces. He invented the hydraulic screw, and new kinds of pulleys, and is said to have built big concave mirrors to focus light

and so to set fire to the siege-engines of the Romans, who were besieging Syracuse. In geometry he arrived at a close approximation to the value of the number called π (pronounced *pi*), which gives the ratio of the circumference to the diameter of a circle: he calculated, quite correctly, that it must lie between $3\frac{10}{71}$ and $3\frac{10}{70}$.

In the second century B.C. a great astronomer called Hipparchus measured the size and distance of the moon with surprising accuracy, and discovered what astronomers call the precession of the equinoxes, which means that the direction in which the axis of the earth points is not always exactly the same, but moves round slowly in a circle—in other words, that the earth wobbles as it spins, something like a top.

In the first century B.C. a good deal of practical chemistry was done, and men began to make dyes and new alloys, and even imitation pearls. Somewhere about this time lived Hero of Alexandria, who invented the first steam-engine, which was, however, only a toy. The last big achievement of Greek science was that of the astronomer Ptolemy, in the second century A.D., who gave a wonderfully complete description of the movements of the heavenly bodies. He believed, however, that they all revolved round the earth, and this meant that his description of the way they moved, though accurate, was extremely complicated.

He also made the best map of the ancient world. At about the same time Galen made some valuable medical and anatomical discoveries, and brought together all that was then known about medicine.

The Romans, on the other hand, made no great scientific discoveries; their talent was more practical. They invented a number of machines which were of great use in

engineering. Julius Cæsar introduced a reformed calendar of 365¼ days, which was much more accurate than earlier ones and came into general use. This calendar was just a little too long, however, so that by the sixteenth century it was eleven days out; Pope Gregory XIII then introduced the calendar we still use, in which leap year is missed every hundred years. The Romans had a very practical knowledge of agriculture, geography, architecture, hydraulic engineering and road-making: they were the first people to have a proper sanitary system and public health service. They were interested in natural history, and Pliny wrote an encyclopædia on the subject: in this, however, there was not much scientific method, and superstition and legend were freely mixed with fact. About the end of the second century, both scientific theorising and practical invention came virtually to a standstill in the ancient world.

Science in the Dark and Middle Ages

When the Roman Empire collapsed, civilisation largely collapsed with it, and almost all of ancient science was lost. Science passed out of men's minds and ceased to influence their actions. Even after the Dark Ages had come to an end, and during the Middle Ages which followed, very little attention was paid to science in spite of the high degree of civilisation attained by the Middle Ages in architecture and art, religion and philosophy, and their achievements in political organisation. For the space of a thousand years there was hardly any scientific advance in Western Europe, and what did exist was dominated and kept in check by theology and philosophy. The spirit of science during a large part of this time was kept alive by the Arabs, who rose to great power as a result of Moham-

med's leadership in the seventh century, and came to exert an influence from Persia in the East to Spain in the West. They studied the remains of Greek science, practised medicine, and made considerable strides in practical subjects like optics and chemistry. They also laid an important foundation for the future growth of science by developing mathematics. The progress they made is still recalled by the fact that *algebra* is an Arabic word[1] (by the way, it is interesting to remember that the great Mohammedan poet Omar Khayyam, who lived in the eleventh century, also wrote an important treatise on algebra).

An even greater mathematical advance is recalled by the name given to our system of numbers—arabic numerals. As a matter of fact, the general system had been invented by the Hindus in India, but the Arabs made it workable by adding the sign 0 for zero. Before that time there was no zero sign; and without the zero sign there could be no proper decimal notation. If you will try to do a simple multiplication or division sum—say, 738 × 14, or 1,248 ÷ 13—in Roman numerals, you will see what an enormous help this new and logical system was to calculation on paper. In point of fact, before this time calculations were generally done by means of the simple counting and calculating machine called the abacus. A great deal of science depends on calculation, and without arabic numerals and algebra even the simplest calculations would be impossibly cumbrous. The Arabs seem also to have been the first to apply the north-pointing properties of magnets—probably first discovered by the Chinese—to navigation.

Another invention which was destined to be of great

[1] The prefix *al*, meaning *the*, marks many words derived from Arabic —*e.g.*, alcohol, alchemy.

help to science in later centuries was that of printing from movable types, which occurred in the fifteenth century. With the aid of this, together with the art of paper-making, which came to Europe from China, scientific knowledge, when it did begin to accumulate again, could spread in a way which was impossible when copying by hand on heavy expensive parchment was the only method of duplicating books.

One of the few Europeans in the Middle Ages to have any record of real scientific experiment to his credit was an Englishman, Roger Bacon, who lived in the thirteenth century. On the basis of his studies he prophesied power-driven carriages and ships and even flying machines. But he was so isolated that his work produced little effect.

It was the Renaissance in the fifteenth century which heralded the dawn of modern science. One reason for the changed spirit was the capture of Constantinople by the Turks in 1453. Constantinople had been the capital of the Byzantine Empire, and many scholars who had lived there sought refuge in the West and brought their knowledge of Greek and many manuscripts of ancient Greek books with them. The revelation of all this ancient wisdom excited the minds of men in the West, and set them searching for new knowledge.

Another reason of a very different sort was the growth of exploration in search of trade. This was made possible by the compass, which was first used in Europe early in the thirteenth century, apparently taken over from the Arabs by the Crusaders. The Portuguese, early in the fifteenth century, explored the coasts of Africa far beyond where any Christian had previously journeyed. The idea that the earth was round came to be generally accepted, and prompted men to search for a new route across the Atlantic

to the rich lands of the East. Everyone knows the sequel —how Columbus at last succeeded, but when he reached the New World thought that he had got to the Indies. The lands he discovered are called the West Indies to this day. Only a few years later Cabot reached the eastern coast of what we now call Canada.

The actual circumnavigation of the earth by Magellan in 1576, the later explorations of the North American continent and of Peru, of South and East Africa, of the East Indies, which took place in the sixteenth century, made a great difference to people's outlook. New countries, new kinds of plants, of animals, of men—here was something to excite curiosity. And the new wealth that flowed into Europe from the gold and silver of America and from the spice trade of the East gave men power and leisure to indulge their curiosity.

The Beginnings of Modern Science

The revival of science, thus prefaced in the fifteenth century, began definitely in the sixteenth century. It is true that Leonardo da Vinci (1452-1519) was a great scientist as well as a great artist and a great engineer, but he never published his results, and so had little influence.

In the first half of the sixteenth century came a great scientific event. The Polish-German astronomer Copernicus gave reasons for believing that, instead of the earth being the fixed centre of all things, it and the other planets travelled round the sun.

About the same time the Fleming Vesalius, who was Professor of Anatomy at Padua, published a great work on the anatomy of the human body, which was the first real advance in this field over the knowledge of the ancient Greeks. Botanic Gardens were first established in Europe

5000 A.D.

2000 — Modern Science. — Great War. Discovery of America. Norman Conquest.

1000 — Arabic Numerals. — Mahomet.

1 A.D. — Galen. Hero. — Roman Empire. Alexander.

Early Greek Science.

1000 B.C. — Trojan War.

2000 B.C. — Babylonian Calendar

3000 B.C. — Great Pyramid.

4000 B.C. — Earliest Cities. Metal-working

5000 B.C.

Agriculture.

Earliest Polished Stone Tools.

Cave-bears die out.

10000 B.C.

15000 B.C.

20000 B.C.

25000 B.C.

Europe inhabited by cave-men with unpolished stone tools.

Last Ice Age.

I. 30,000 years, from the last Ice Age.

30,000 YEARS

2000 A.D.

[Species. Darwin: Origin of — Boer War.

Dalton: Atoms. — Battle of Waterlo

Watt's Steam Engine. — American Revolut n.

Newton: Principia

Harvey. Galileo. — Charles I. behead .

Gregorian Calendar. — Spanish Armada.

Copernicus. Vesalius

1500 — Leonardo da Vinci

Discovery of Amer a. Printing. Fall of Constant nc e

Roger Bacon First Oxford Colleges. — Magna Carta.

Introduction of Arabic Numerals. — 1st Crusade. Norman Conquest

1000 — Arabs improve Algebra.

Charlemagne. Moors conquer Sp n.

Mahomet.

500 — Fall of Rome. Barbarian Invasions.

Constantine.

Ptolemy. Galen. Hero of Alexandria — Marcus Aurelius.

Capture of Jerusa n.

1 A.D. — Augustan Age. Death of Cæsar.

Calendar of J. Cæsar.

Hipparchus. — Carthage destroy .

Archimedes. — Great Wall of Ch a. 1st Punic War.

Euclid Aristotle. — Alexander.

Socrates. — Plague of Athens Marathon.

500 B.C. — Cyrus. Captivity of Juda

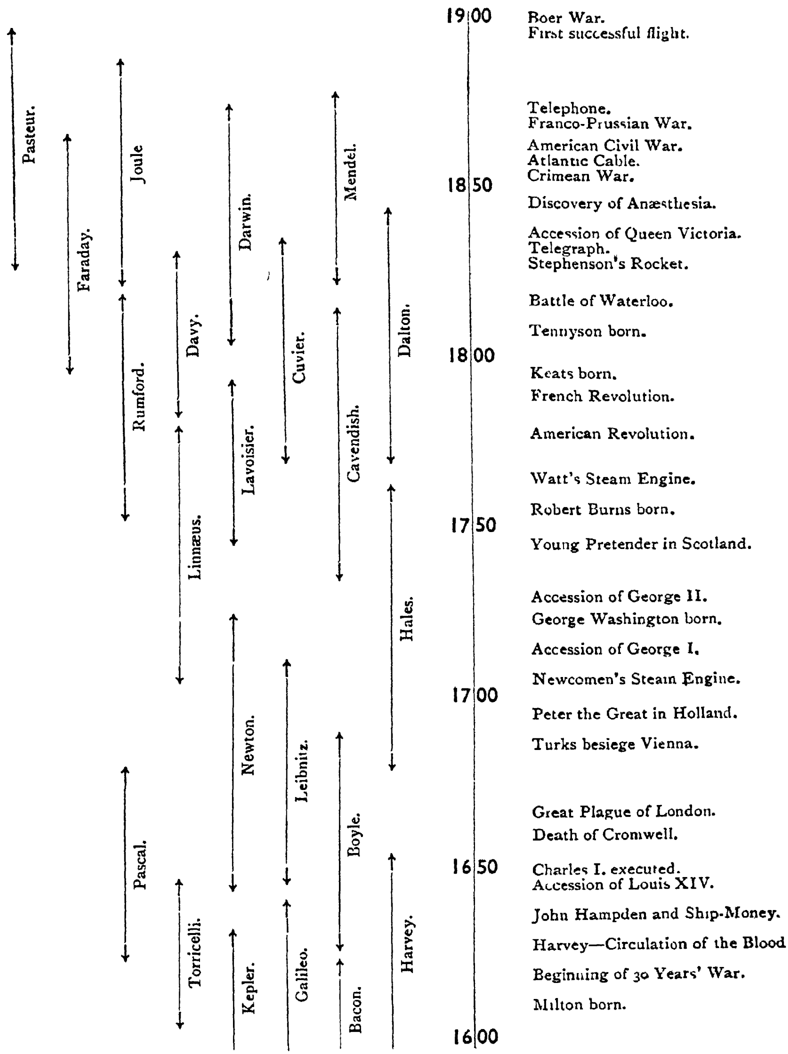
Early Greek Science. — Sennacherib. Captivity of Isra Elijah

Solomon.

1000 B.C.

II. 3,000 years, from 1000 B.C.

3,000 YEARS



III. 300 years, 1600—1900.

300 YEARS (1600-1900)

about this time, and plants began to be studied systematically. One of the most noted scientists of the second half of the sixteenth century was John Gilbert of Colchester, who studied magnetism and electricity. To him we owe the word *electricity* (from the Greek for "amber," because amber when rubbed becomes electrically charged). He was the first to point out that the earth itself acts as a vast magnet.

So the fifteenth century paved the way for the rise of modern science, and the sixteenth saw its scattered beginnings; but it was the seventeenth in which it first became an organised movement and really began to gather momentum. Early in the century Lord Bacon wrote the first book setting forth what the method of natural science ought to be, and what practical results might be expected from it.

The astronomer Kepler (1571-1630) took up Copernicus' ideas about the movements of the earth and the planets round the sun; but whereas Copernicus had imagined they moved in circles, Kepler showed that they actually travelled in ellipses, and discovered some very important facts about their speed at different parts of their path.

The famous Italian Galileo (1564-1642) was the greatest scientist of his time. The telescope had recently been invented, and he revolutionised astronomy by the use of an instrument magnifying 30 diameters. This showed him that the surface of the moon was not smooth but covered with mountains and valleys like the earth. (Milton, by the way, visited Galileo, and in *Paradise Lost* describes the face of the moon as seen through this early telescope.) Galileo's telescope also showed him that the Milky Way, which had puzzled men since the earliest

ages, was made of innumerable but very distant stars. It showed him four moons circling round Jupiter. He firmly established the truth of Copernicus' idea that the sun, not the earth, is the centre of our system.

But it was in mechanics that he made his greatest discoveries. He showed by experiment that, contrary to all the opinion of the learned men of the time, heavy bodies did not fall faster than light ones. He was the first to discover the law governing the speed of falling bodies — what we now call uniform acceleration — which is at the basis of much of dynamics and their practical applications like the calculation of the path of a projectile fired from a gun. He showed that motion, once acquired by a body, would continue indefinitely unless checked by some external force. This again was a wholly new and revolutionary idea: everyone else had supposed that force was continually necessary to keep a body in motion.

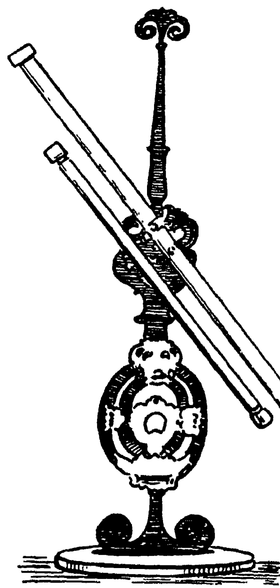


FIG. 153.—*Early telescopes were small and did not magnify much. The telescope used by Galileo.*

In all these ways he prepared the way for that other great man, Isaac Newton, who was born in the same year that Galileo died. Newton's most famous discovery was the principle of universal gravitation—the idea of a force exerted by any massive body

such as the earth, pulling other bodies towards it, an diminishing in proportion to the square of the distanc from its centre. He proved that such a force would nc merely make a stone or an apple drop, but would prever the moon from flying off into space and would keep circling round the earth. Similarly it would keep the eart and the other planets circling round the sun.

Furthermore, he showed that the paths described by tl planets and their satellites should, if this law of force wei true, be ellipses, as Kepler had actually discovered the to be. And his calculations accorded with fact to a r markable degree of accuracy. Thus instead of the plane having to be guided in their courses by supernatural inte vention or by some quite mysterious and unknown forc he proved that their movements could be explained c simple mechanical principles no different from tho governing the fall of a stone to earth. With this, the idea general scientific laws operating everywhere in the univer first became firmly established. It meant a new outloc on nature.

Newton made discoveries of almost equal importan in other branches of knowledge. He and Leibnitz, tl German philosopher and mathematician, share the hono of inventing the mathematical method that we call tl differential calculus, which is of immense use in studyi any scientific problem in which the rate of change of a pr cess is involved. He proved that the tides were due to tl gravitational attraction of the moon and sun in combin tion. He first made fully clear the idea of the invariat *mass* of a body, as distinct from its *weight*, which is t gravitational force attracting it. The mass of a body the same everywhere: its weight may vary. For instanc the same body would weigh less on the moon than on t

earth, because gravity is less on the moon. He was the first to explain clearly what happens when white light is split up by a prism into a spectrum of differently coloured lights, and to give a satisfactory explanation of the rainbow. Another important discovery of the same period was made by the Danish astronomer Römer—that light was not propagated instantaneously, but took time to travel.

Considerable advances were also being made in physics. Robert Boyle and others showed that air is a material substance, with a definite weight, thus proving true the long-forgotten speculation of an ancient Greek. Boyle also discovered the law about the pressure and the volume of air and other gases—that doubling the pressure halves the volume, trebling the pressure makes the volume decrease to one-third, and so on. Another of his discoveries was that the temperature at which water boils depends on the pressure of the air upon it, and he made many important experiments in chemistry. He finally disproved the idea that fire was an "element," or that it was always the same and always resolved substances into their elements. He came very near the modern idea of chemical elements.

About the same time the Italian Torricelli invented the mercury barometer, and the Frenchman Pascal, who was a great theologian, mathematician, and writer as well as a scientist, showed that the height of the mercury column in the barometer went down as he ascended a mountain. Thus he proved that the mercury column was held up by the weight of the air above, and so laid the foundation of modern weather-science or meteorology.

Meanwhile in biology a very fundamental advance had been made. William Harvey (1578-1657), court physician to Charles I, discovered the circulation of the blood, a fact

upon which all modern physiology and medicine is based. The ancients had supposed that the blood pulsed out from the heart and back in an ebb and flow like that of the tides. The idea that in some blood-vessels (the arteries) the blood is always flowing away from the heart, and in others (the veins) is always flowing back into it, was quite new. Harvey was led to this discovery not only by experiment and careful dissection, but by calculation. By finding how much blood the heart drove out at each beat, and measuring the rate of beat, he showed that in half an hour it must pump as much blood as there is in the whole body. He also made many observations on development, and was the first to assert that all living things develop from an egg (though his ideas of exactly what an egg was were not quite what we hold to-day).

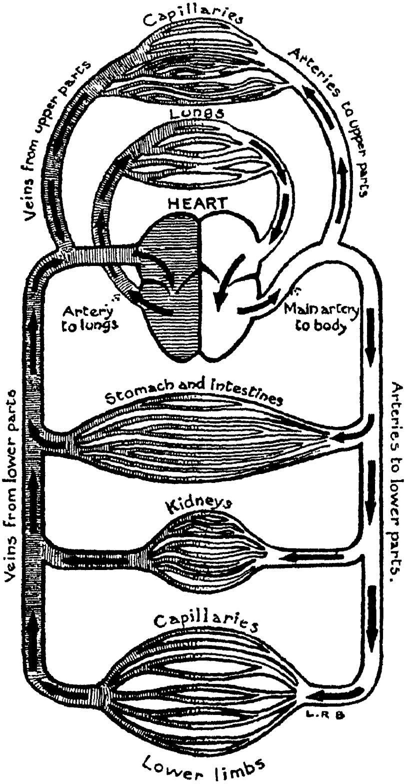


FIG. 154.—*A diagram to show the circulation of the blood in a man. Blood rich in oxygen is shown white, blood poor in oxygen and rich in* CO_2 *is shown shaded. The capillaries are really very much smaller in proportion.*

The invention of the microscope gave a further impetus to biology. Using this new instrument, Malpighi actually saw the capillaries or tiniest blood-vessels, through which

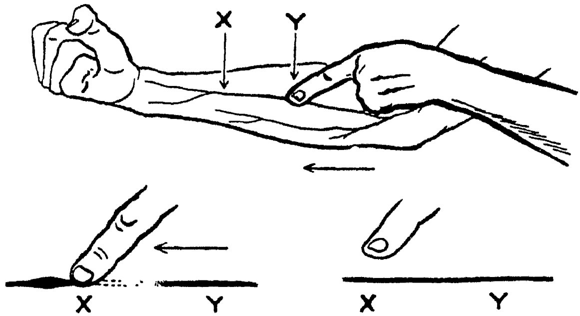


FIG. 155.—*Harvey's experiment with veins: (above) press a finger on a vein at* Y*; (below) left, move the finger up to* X*: the blood is squeezed out of the vein between* Y *and* X*; (below, right) take the finger away: the empty part of the vein at once fills up again.*

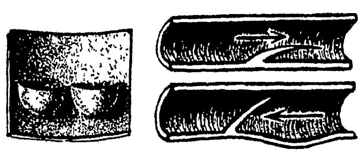


FIG. 156.—*How the blood is kept moving in one direction through the veins. Left, a piece of a large vein opened up and spread out flat to show a pair of valves. Right, a diagram to show how the valves work. Above, when the blood is flowing towards the heart, it can pass the valves; below, if it tries to flow in the opposite direction, the valves prevent it.*

the blood circulates from arteries to veins. Harvey had never seen the complete circulation: he only proved that it must exist. The microscope also enabled Malpighi to give the first detailed account of the earliest stages of

development in the chick, when it is still extremely small. In Holland, Leeuwenhoek devoted himself to microscopical work, studied many previously unknown forms of life invisible to the naked eye, and was the first man to see bacteria, blood-corpuscles and sperms.

About the same time, the English botanist Nehemiah Grew studied flowers, and was the first to understand that

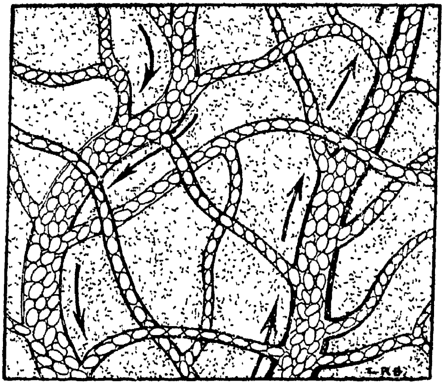


FIG. 157.—*How the blood circulates in a frog's foot, as seen under the microscope. A small artery is shown on the right. It sends its blood out into tiny capillaries, which join up to make veins. There is a small vein on the left.*

the stamens and the pistil were the male and female organs of reproduction in plants. He and other scientists of the period established the need for pollen from the stamens to reach the pistil if the flower was to set seed.

Along a rather different line, another Englishman, John Ray, made a beginning with the proper classification of living things, first of plants, and, later in his life, of animals. Before his time, natural history had been little

more than a jumble of miscellaneous facts. He began to show that there was underlying order and rule.

An important step in the history of science was the founding of learned societies, like our Royal Society, to discuss scientific discoveries and theories, and to publish accounts of them. Already in the sixteenth century one such body had been founded in Italy, but it was only in the seventeenth century that they became important. The Accademia dei Lincei in Rome (Lincei means "lynx-eyed," because the lynx was supposed to have especially sharp sight), the Royal Society in London, and the Académie des Sciences in Paris were all founded during this century, and all still exist and flourish.

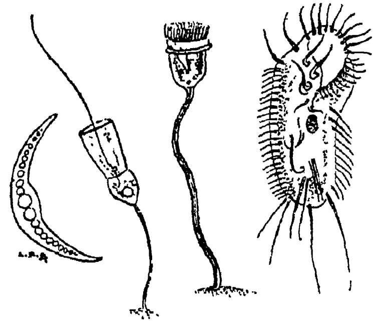


FIG. 158.—*Types of minute creatures rendered visible to human eyes by the invention of the microscope. Left to right, a tiny plant (Desmid); and three animals—a collared flagellate, with a long whip-lash with which it makes a current to bring in food; a bell-animalcule (Vorticella) with contractile stalk, which also makes a food-current, but by means of tiny hairs or cilia; a free-swimming ciliate called Stylonychia.*

Eighteenth-Century Science

During the eighteenth century, scientific advance was on the whole not so exciting or far-reaching as in the seventeenth; but a great deal of solid work was done, and new facts and ideas advanced.

In geography a great many previously unknown countries and seas were explored and charted. This fresh out-

burst of scientific exploration was made possible by improvements in navigation. These in their turn were due partly to Newton's work, which enabled the position of the moon among the stars to be predicted mathematically, and partly to the invention of accurate chronometers by the English clockmaker Harrison.

In biology, the work of Ray was improved and extended by the great Swedish naturalist Linnæus. Not only did Linnæus put forward an improved classification, but he invented a convenient and handy system of naming animals and plants which, in slightly modified form, we still use to-day. Instead of giving a name in the form of what was really a description, he laid down that every living thing should have a name of two words only—one to denote the general kind, and one for the particular kind, rather like our surnames and Christian names. The names were all to be in the universal language Latin (or latinized Greek), and the "surname" came first. Thus he classified the house-mouse and the black rat together under the common "surname" *Mus* (Latin for "mouse") and distinguished them as *Mus musculus* and *Mus rattus* respectively. It would have been as impossible for biologists to deal with the huge number of living things later discovered (about a million different kinds are now distinguished) without this simple system of naming as it would have been for arithmetic to have developed properly without the simplicity of the decimal notation. During the same period the Count de Buffon wrote the first modern treatise on Natural History

Other notable advances were made in biology. Red and Spallanzani in Italy showed that at any rate the larger forms of life could not be generated spontaneously Spallanzani, too, made many discoveries about digestion and reproduction. At the same time Haller, in Germany

not only made discoveries himself, but also gave an account of the workings of the body, which was the first general treatise on physiology.

From this time, too, dates the first investigation of the power of animals like newts and lobsters to regenerate or re-grow lost parts, and the discovery that some animals could regenerate themselves entire even if chopped into fragments. Réaumur in France was the first to make a

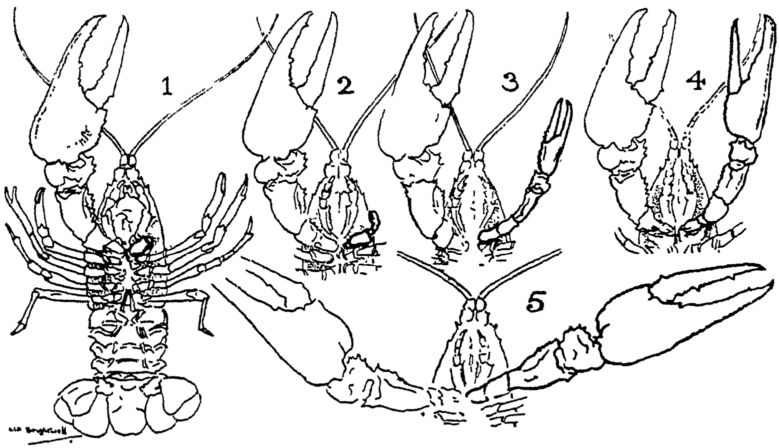


FIG. 159.—*A crayfish can regenerate a lost limb.* 1, *One of the big claws has been broken off, and the wound has healed over;* 2, *at the next moult a tiny claw has been formed;* 3, 4, 5, *this grows gradually to full size.*

proper study of the habits of bees and ants, while Hales in England was discovering many important facts about how plants get their food (Chapter V, p. 196).

But the most important advances were in chemistry. Henry Cavendish succeeded in combining the gases we now call hydrogen and oxygen to form water, and thus

proved it was not an element, as had been almost universally held till then. Different gases were prepared in the pure state by various scientists, among whom Joseph Priestley is the best known. Finally Lavoisier in France (who was afterwards guillotined during the French Revolution, his judges proclaiming that "the Republic has no need of learned men") established that these gases were really different pure substances, and not just different varieties of "air," and cleared up the nature of combustion and respiration and the meaning of flame.

All sorts of erroneous ideas had previously been held about flame and the process of burning. The most prevalent had been that there existed a definite substance, which was christened phlogiston, or fire-substance, which escaped from materials when they were burnt. As it had been already established that when metals were burnt they increased in weight, this supposed phlogiston had to have a negative weight, and this notion of a substance with a negative weight had muddled people's notions of the nature of matter and the processes of chemistry. Oxygen, for instance, was called by the confusing name of "dephlogisticated air." Lavoisier, by accurately weighing all the substances concerned in burning, the gases as well as the solids, showed that combustion could be quite simply explained as the result of the combination of a definite substance—oxygen gas, which had weight like any other substance—with the material that was burnt. He also finally clinched the idea that breathing is of the same nature as burning, only taking place much more slowly. Breathing, rusting and burning are all oxidation.

Nineteenth-Century Science

With the nineteenth century, the discoveries and applications of science become ever more crowded, so that we can here only tell of a few of the most important. In chemistry, Lavoisier's accurate work paved the way for a great generalisation. Early in the century, Dalton (1766-1844) showed conclusively that chemical combination could best be understood if the simple substances, the elements, that reacted were made up of innumerable invisible particles, the atoms. His work was soon extended through the notion of molecules. A molecule is the smallest particle of a particular substance, while an atom is the smallest particle of each ultimate kind of matter or element. Thus the molecule of oxygen gas is O_2—two atoms of the element oxygen. The molecule of sulphuric acid is H_2SO_4. There had been general ideas in chemistry before this, such as the Greek idea that there were four "elements," earth, air, fire and water; or the idea of the alchemists of the Middle Ages that there were three elementary "principles" at work in chemistry—sulphur, or the fire principle; mercury, or the liquid principle; and salt, or the solid principle. With the progress of knowledge, these ideas were found not to hold good. The idea of atoms is the general idea which underlies all modern chemistry. With its help, all kinds of advances were made in chemical knowledge.

To start with, new elements were rapidly discovered. Sir Humphry Davy succeeded in decomposing soda and potash by means of electricity, and so discovered the strange metals sodium and potassium. Later the invention of the spectroscope revealed many new elements. Delicate new methods of gas analysis showed that the air contained, besides oxygen and nitrogen, a number of other gaseous

elements, of which we may mention neon, now much used in electric signs, and argon, employed to fill electric light bulbs. Later still, the study of radio-activity led to the discovery of radium, and other new elements. We now know that the earth and everything in and on it is made of about ninety different kinds of matter or elements, arranged in different ways to form the innumerable different chemical substances that exist.

The main lines of chemistry, both inorganic and organic chemistry, were discovered in this century. Especially notable was the proof that substances normally found only in living animals and plants could be made artificially in the laboratory; the deliberate building up of many new chemical substances not found in nature, including many useful drugs and dyes; and the discovery of catalysis, or the way in which certain substances will speed up chemical reaction.

The detailed study of current electricity was made possible by Galvani and Volta in Italy, and many discoveries about it and its action speedily followed. These included the deposition of metals from solution of salts, which led to electroplating; the generation of heat by the passage of a current, which we utilise to-day in electric heating; the remarkable discoveries of Oersted and Ampère about the effect of currents on magnets and on each other, which soon led to electric telegraphy; and the wonderful researches of Faraday, showing that electric currents could be induced by moving a magnet through a coil of wire carrying a current, and in other ways, which laid the foundation of our use of electric power.

Another great advance was in regard to heat. It had long been supposed that heat was a sort of fluid. But just before the middle of the century, following up some idea

of Count Rumford, the Englishman Joule showed that either mechanical or electrical work would generate heat, and accurately measured the amount generated, so proving that heat was a form of energy. This led to the establishment of the idea of the Conservation of Energy—in other words, that there is a certain fixed amount of energy in the world, but that it can show itself in different forms—heat, mechanical, electrical, or chemical energy—and can be converted from one form into another.

Since the chemists had previously established the indestructibility of matter even when to common sense it seemed to disappear, as in burning, science now was provided with a broad principle of the most general application—that neither matter nor energy were destroyed in all the different happenings of nature. They might be changed from one form into another, but the sum total remained always the same.

Meanwhile, in other branches equally great advances were being made. Geology, as we have described in Chapter II, came into being as a definite science. The origin of the rocks of the earth's crust, the difference between sedimentary and igneous rocks, the succession in time of different rock-layers, the nature and meaning of fossils—all these were studied in the early years of the nineteenth century. The broad principle of Uniformitarianism was established—meaning that the processes going on in earth-history must be thought of as more or less uniform, and that, if enough time is available, the accumulated results of tiny slow changes, similar to those we see around us to-day, will account for geological happenings, even on so huge a scale as the formation of thousands of feet of sedimentary rock-layers, the carving of deep gorges and wide valleys, even the raising or lowering of the con-

tinents. The rival theory was called Catastrophism, and thought that we could only account for such facts on the idea that at intervals in the earth's history terrific catastrophic events took place, like a sudden vast flood, or the splitting of the earth to form gorges.

This idea of catastrophism gradually died out in general geology, thanks largely to the work of Sir Charles Lyell in England. But it lingered on as regards the history of life. Baron Cuvier, the great French zoologist, who also advanced our ideas on animal classification, was the first to make a really extensive study of fossil animals. He showed that the mammals living in Western Europe in earlier geological periods were quite different from those of to-day, and that those of one main period differed from those of another. He advanced the view that the animals of each age were extinguished by some great catastrophe, like a flood, at the end of each period, and that then a new set of different kinds of animals was created at the beginning of the next period.

Gradually, however, as more facts were studied, it was seen that this idea would not work. Finally Charles Darwin (1809-1882) demonstrated that the different kinds of animals and plants were not created as they exist to-day, but have gradually changed or evolved from quite different earlier kinds.

In Chapters II and VII we have told about this, and about the theory of Natural Selection, which he was the first to advance to account for evolutionary change. For a time, some people struggled against the idea that evolution could account for the origin of man as well as that of lower animals. However, conclusive facts were gradually amassed, such as the close resemblance of man's construction to that of the apes, the existence of an early stage in

man's development when he has gill-clefts like a fish, and a later stage when he still has a tail and is covered with hair, and the discovery of fossil remains of creatures intermediate between apes and modern men. Finally it became plain that all creatures, including ourselves, are the result of a long slow process of evolution, guided by the automatic mechanism of natural forces like Natural Selection. This of course meant a complete change from the older outlook, which thought of man as purposefully designed and created a few thousand years ago, and of all other living things as having been created at the same time for his use and enjoyment.

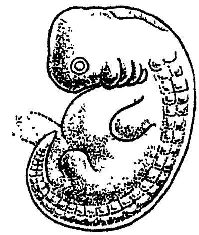


FIG. 160.—*An embryo human being, at a stage when the limbs are mere buds without fingers or toes. It has a tail, and in the neck-region are clefts which correspond with the gill-slits of a fish, like a dogfish or shark.*

During the rest of the century much of zoological research was devoted to studying animals, their structure and habits, their distribution in space and time, and their development, from the new angle made possible by Darwin. The classification of the animal and plant kingdom was finally put on a proper footing when it was realised that the basis of classification must be relationship—that if you classed together a number of animals like dogs, bears, weasels and cats in the group of Carnivora, it meant that they were all related by descent from a common original stock; and if you classed a number of other animals like lemurs, monkeys, apes and men in another group of Primates, and then classed the Carnivora and the Primates together in the larger group of Mammals, it meant that the common stocks of Carnivores and Primates, if you could trace them still further back

in geological time, would both be descended from another single but still more original stock which would still have had the characteristics of Mammals in general, such as being covered with hair and suckling their young with milk.

FIG. 161.—*Men were not always so human as now: a family of Neandertha men. This type of man lived more than fifty thousand years ago, an was more ape-like than modern man in a number of ways (receding forehead and chin, bent legs, big jaw and teeth, bony eyebrow ridges, etc.)*

During the same period, the process of fertilisation c the egg was observed for the first time—by the pollen-tub in plants, by the sperm in mammals; and the principle o the stream of life and its continuity (Chapter VI) wa established. The great French scientist Pasteur showe that this was just as true for bacteria and other microscopi creatures as for familiar animals and plants. By provin

that spontaneous generation did not occur, he enabled us to understand what happened in decay, laid the basis for the germ-theory of infectious diseases, and made modern surgery possible.

The beginnings of scientific agriculture also date from this time (Chapter V).

Later in the century, great advances were made in physics and in astronomy. Both X-rays and wireless waves were discovered, and were shown to be of the same general nature as light. Later came the discovery of radium and radio-activity, and this has recently been leading to quite new ideas about the atoms of which matter is made up: it turns out that they are not the ultimate units of matter after all, but themselves, in spite of their incredibly small size, have a complex structure of still smaller units (electrons, etc.).

In astronomy, by means of new instruments like the spectroscope on the one hand, and improvements of old instruments like the telescope on the other, wonderful discoveries were made about stars: the material of which they are made, their temperature, their speed and the direction in which they are travelling, their size, their enormous numbers, and the strange way they are grouped in space.

About the same time the work of Mendel (Chapter VII), which had lain unnoticed for over thirty years, was brought to light, and very rapid progress was made in our understanding of heredity. Also quite new discoveries were made about the way the human mind works, notably by Charcot and Janet in France and by Freud in Austria, and psychology or the science of mind began to develop very rapidly.

However, with these discoveries we are entering on the twentieth century, and it would be impossible here to go into all the details of the very recent progress of science since that date.

CHAPTER IX

SCIENCE AND GENERAL IDEAS

Scientific Methods and Principles—Science and General Ideas—Scien and the Control of Nature—The Main Steps in the History of Science- The Succession of Subjects Studied by Science

Scientific Methods and Principles

THERE are so many details in science, so mar separate discoveries and new ideas, that at first sigl the history of science seems a confused jumble of fact But if we look back over it, we can pick out certain poin which have general interest, and this will help us to unde stand better what science is and what it means.

First of all, science means finding out how thing actually *do* happen, not laying down principles as to ho they *ought* to happen. The most famous example of th concerns Galileo's discovery about falling bodies. As w saw, he showed that, excluding the slight difference dı to air-resistance, a light object falls to the ground at tl same rate as a heavy object. This did not agree with tl views of most learned men of the time. They had take over from Aristotle the idea that there were two opposir "principles" in objects—a "heaviness principle" that mac heavy things like lead weights fall downwards, and "lightness principle" that made light things float upward In various materials, these opposing principles were suj posed to exist in varying proportions. However, Galil proved his point experimentally by dropping differe weights from the Leaning Tower at Pisa: if they we

dropped at the same moment, they reached the ground at the same moment. Even then, many of the learned men would not be convinced. They believed so much in their principles that they said there must be a flaw somewhere in Galileo's experiments. But Galileo was right, and the facts he established and the laws he discovered about them are the basis of our modern knowledge of mechanics, of astronomy, and of many very practical things, like the range of rifle-bullets and shells.

Other people at first refused to believe that the earth went round the sun, because it contradicted their established beliefs. But the facts were too much for them, and after a time it was universally acknowledged that the earth *does* go round the sun.

In antiquity, and still more in the Middle Ages, this passion for first setting up general principles and then trying to explain things by means of them was very prevalent. It, and not the scientific method of first observing facts and making experiments and then drawing general conclusions from them, was the usual way of thinking about nature. Sometimes it had very curious results. For instance, there was the supposed principle that some things and forms were more perfect than others. The circle was regarded as the most perfect form. The heavenly bodies were regarded as perfect, in opposition to the earth and all it contained, which was full of imperfections. As a consequence, it was concluded that the heavenly bodies must all move in circles, for a body which was perfect could, it was argued, obviously not move in a track whose shape was not perfect. This idea influenced astronomy right up to the sixteenth century, when Kepler finally showed that whether the heavenly bodies were perfect or not, they moved in ellipses. Later, when in the seventeenth

century Galileo's telescope showed that the moon was of the same general nature as the earth, the whole idea of the "perfection" of the heavenly bodies had to be dropped.

Again, in the Middle Ages, the male sex was regarded as more perfect than the female. Accordingly it was seriously stated by some writers that cockerels would hatch from more rounded eggs, because the shape of these was nearer to a circle than the pointed eggs, which would produce pullets. If anyone had taken the trouble to try an experiment, they would at once have seen that there was no truth in the idea.

Sometimes people who held strongly to preconceived principles went even further. When Galileo with his newly invented telescope showed that the moon had mountains like the earth, and Jupiter had satellites circling round it, the Professor of Philosophy at Padua refused to look through the telescope. He did not *want* to see something which went against his beliefs.

Obviously this was very unscientific. The only way to get new knowledge is to try to find out some new fact. The only way to know if an idea is true is to test it out against facts. However, this kind of attitude is not uncommon. We all have our beliefs and prejudices, often unconsciously, and generally do not like to have them upset. You often hear people saying that some idea or fact *cannot* be true because it goes against common sense. However, common sense is just a name for the notions we get from ordinary experience and from the ideas in which we have grown up. It is common sense for us to take certain kinds of precautions against infection with the germs of certain diseases, because to-day we know about bacteria: but it is not common sense for the savage, who knows nothing about bacteria and believes firmly that disease is due to magic.

For him it is "common sense" to look for the witch who is responsible, or to try to charm away the disease by counter-magic. When the question was being discussed whether the earth was flat or spherical, many people said it could not be round because people at the Antipodes would be upside-down, and that was against common sense.

So one of the most important things in science is not to pay attention to prejudices and preconceived ideas, whether these take the form of so-called common sense, or undue belief in authority or philosophical principles. Observation and experiment are the only final authority in science.

This is the great difference between science and magic. Savages believe firmly in magic, and a great deal of their lives is concerned with performing magical rites. Some of these are supposed to make the crops grow, or to bring rain, or to secure success in hunting or in war. In many parts of Africa, even to-day, the idea that people die of natural causes is unknown: death is always supposed to be due to some sort of witchcraft or black magic; and accordingly much magic is practised in the hope of curing diseases.

Some magic depends on the idea that imitating an event in make-believe will bring it about in reality. A common form of "black magic" was to make an image of your enemy in wax, and then, to the accompaniment of spells, stick pins into it or melt it before the fire. This was supposed to cause the person's death. Hunting magic often consists in dances where some of the hunters dress up and act like wild animals and the others pretend to kill them.

Another "principle" of magic is that objects can be possessed of mysterious powers, and so become charms or talismans, or work good or evil. Generally such objects

have something queer or striking about them, like the odd-shaped stones or trees that serve as fetishes in parts of Africa; or they are associated with some remarkable person, or sacred place, or strange occurrence.

It is clear that in both these cases (and the same is true for other kinds of magic) a definite idea or principle is behind the minds of the men who believe in and practise the magic. The trouble is that, like some of the other principles we have been discussing, these too happen to be wrong.

Science and General Ideas

One of the main reasons why such wrong ideas and useless practices can grow up is ignorance. Among primitive tribes to-day, as was the case too in prehistoric times, there is hardly any scientific knowledge: everything is mysterious. The sun rises and sets and the moon changes, but people have no idea why, or what are the relations of the heavenly bodies to the earth. No one knows anything about the natural causes of rain or drought, storms or earthquakes, famine or disease. Accordingly everything is put down to mysterious influences by magic or by good and bad spirits. Such ideas cannot very well be called superstitions so long as no better explanation is available. But reason may show that they are false, and finally, when scientific knowledge demonstrates the way things really work, the ideas of magic or spirit-influence can be seen to be mere superstitions.

So as science progresses superstition ought to grow less. On the whole, that is true. But it is surprising how superstitions linger on. If we are tempted to look down on savage tribes and other nations for holding such ideas, we should remember that even to-day, among the most civilised

nations, a great many equally stupid superstitions still exist and are believed in by a great many people. It is worth while making a list of the superstitions which you know about. Some people will not sit down thirteen at table; others will not light three cigarettes from one match, or do not like to start anything important on a Friday, or refuse to walk under a ladder; many people buy charms and talismans because they think they will bring luck. Perhaps you yourself are inclined to believe in some of these ideas! Try to find out if there is really anything in any of them, and what reasons there may be for people believing in them.

Probably the most terrible example of superstition is the belief in witchcraft. In Western Europe, during the sixteenth and seventeenth centuries, over three-quarters of a million people were killed, mostly after being tortured, because they were found guilty of witchcraft—something for which to-day we can find no scientific evidence. When people give reasons for persecuting others, we ought to be very sure that their reasons are not merely superstitions, or based on false principles.

Furthermore, even in civilised nations to-day, many actions take place and laws are framed on the bases of principles which are just as much unproved assumptions as were many of those of the philosophies of the Middle Ages. For instance, it is often held as a principle that white people are inherently superior to people of other colour. This is rather like the "principle of perfection" we have just mentioned. In the same sort of way the ancient Greeks believed themselves inherently superior to the barbarians of Northern and Western Europe. The only way to see if there is anything in such a principle is to make scientific studies of numbers of white and black

and brown people under different conditions of life and education and find out just what they can and cannot achieve.

It is, however, true that the increase of scientific knowledge does reduce superstition and also baseless speculation and useless argument and practices. Civilised people do not take sides and get angry about the composition of water: the composition of water is known, and there is no argument about it. They may be frightened at a volcanic eruption or an outbreak of plague; but they do not try to propitiate mysterious powers to stop the eruption, or blame the plague on the sins of their enemies or on the machinations of witchcraft.

These are examples of the fact that the advance of science necessarily changes our general ideas. We will mention one or two other examples. The advance of astronomical science has entirely changed our views as to the place of man in nature. Before the time of Copernicus, it was universally believed that the universe was quite a small affair, that the earth was its centre, that the sun and moon existed to give light to our world, and that they and the stars travelled round the earth. Since then, there have been many changes in our ideas, until now we know that the earth travels round the sun; that the sun is only one of millions of stars, which are scattered in space at distances of millions of millions of miles; that all the stars we see make up only a single star-family, and that there are millions of other similar star-families swimming in space at almost inconceivable distances, but visible through our telescopes as spiral nebulæ (Fig. 162). We can no longer think of man or his home as in any way central, or as being anything but very insignificant compared with the universe as a whole.

The advance of biological science has had an equally great effect. Before the nineteenth century it used to be supposed that man was created only a few thousand years ago in the same form that he has to-day, and that

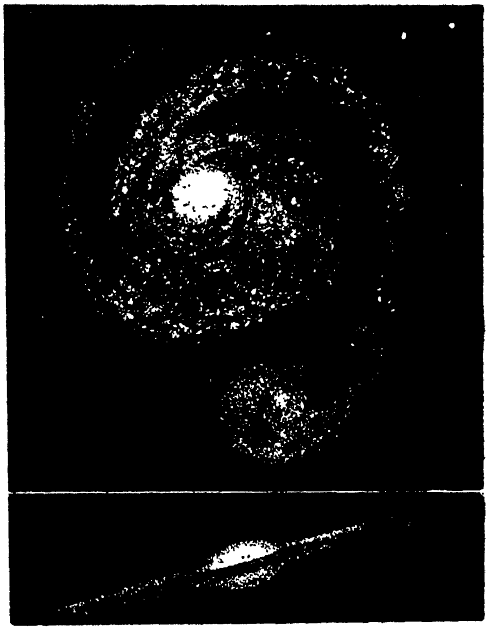


FIG. 162.—*Spiral nebulæ, as seen through a powerful telescope. Above, one seen in face; below, one seen in side view.*

all other animals and plants existed for his benefit. The discoveries of geology proved the world to be enormously old, and Darwin and his followers showed that man had evolved from an animal ancestor. To-day we know that life has existed on the earth for over a thousand million

years; that during that time it has slowly changed or evolved into many different forms; that man evolved out of an ape-like creature, and came on the scene very late in the world's history; that he has changed in various ways during his evolution; and that there is no reason why further change and evolution should not take place. Furthermore, the rest of life does not exist to serve man: man simply happens to be the most successful living creature, and to be able to use many animals and plants for his own ends.

There are many other ways in which scientific knowledge has changed general ideas—for instance about heredity, and castrophes like earthquakes, and disease, and the religious beliefs of primitive peoples; but we have not space to go into them here. When studying history, it is a good exercise to try to trace the effects of scientific advance on the ideas prevalent in different periods.

Science and the Control of Nature

But science not only provides knowledge about nature: it also provides means for controlling nature. So besides general ideas, science also affects practical affairs and every-day life. Perhaps the most obvious example concerns transport. Up to the end of the eighteenth century, transport on land differed very little from what it had been in Roman times. A Roman officer in second-century Britain could get from London to York just about as quickly and comfortably as an eighteenth-century English gentleman. Owing to the compass and to improved design of ships, sea transport had improved a little, but not very much. Then came the invention of the steam-engine, and its improvement, which was dependent on the general scientific knowledge of the time. Steamships, and

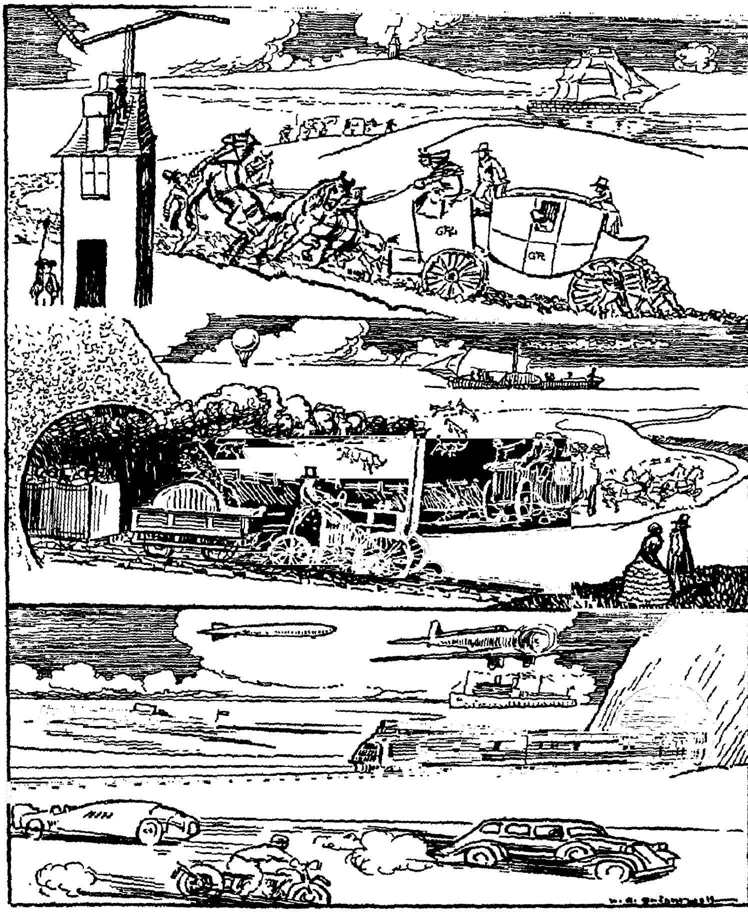


FIG. 163.—*Science and transport. Above, a scene from the time of the French Revolution. The roads are very bad, and pack animals are still used. Messages were signalled by semaphores on towers: this was the first telegraph system. Centre, in the very early days of railways, about 1830. The roads were much better, but steam-engines were being increasingly used. Balloon ascents were sometimes made. Below, a modern scene: flying, stream-lining, smooth hard roads; greater speed and greater power.*

railways with steam locomotives, completely changed the business of travel and of the transport of goods. The internal combustion engine, again based on the scientific study of heat and its generation by gas explosions, made possible first the motor-car and the Diesel engine and then the aeroplane. Now people are talking of the possibilities of flying at five hundred miles an hour or more by means of rocket-propulsion in the thin higher layers of the atmosphere. It is interesting to note down the highest speeds possible for land, sea and air travel every ten years from 1820 to the present day.

Similarly with communications. Not only did the steam engine, and then the aeroplane, speed up the sending of letters and newspapers, but the discoveries about electricity made possible first the telegraph, then the telephone, and then wireless; and to-day television is on the verge of becoming practical. As a result of science, the possibilities of tying the world together by quick transmission of facts and ideas have completely changed in less than a century.

Or again, think of the lighting of houses and streets. Candles—oil lamps—gas—arc lights—electric filament lamps—and now vapour-discharge lighting. Or sanitation—all that it means to have pure water in every house. Or the difference between a surgical operation before anæsthetics and aseptic methods, and a surgical operation to-day. Not only has science provided all kinds of new substances and machines and sources of power, but in so doing it has changed our everyday life.

However, we should not imagine that the practical applications of science are always necessarily a benefit. We have already described (Chapter III) how recklessly men are exploiting the resources of nature. This waste

would not be possible but for the applications of science. Our industrial civilisation makes new demands for sources of power: mining responds with increased activity and new scientific methods for getting coal and oil more cheaply and more quickly. Improved transport brings men more easily into the remote parts of the earth, and enables them to kill the wild creatures. The applied science which makes it possible for everyone to have their morning newspaper causes the reckless cutting down of forests to provide wood-pulp for news-print.

Again, without science, modern cities would be impossible. Applied science transports people from their homes to their work and back, provides them with concentrated fuel in the shape of coal to heat their homes and run their factories (wood fuel could not have served), brings them refrigerated food from the countryside and even from distant countries, gives them sanitation and pure water and so on. But once big modern cities have thus come into being, they bring new problems. Smoke is one of them. Burning raw coal causes smoke to hang like a pall over most industrial cities. The smoke contains acids which corrode buildings and damage plant-life: it is dirty and means more cleaning and washing; it forms a haze and so cuts off the ultra-violet rays of the sun, which we now know are important for health; it makes it easier for fogs to form, and causes them to be dark and dense and full of injurious substances, and these fogs are the cause of much unnecessary disease.

Health is another problem of modern city life. Apart from the damage due to smoke, cheap foods are often deficient in one or other of the vitamins necessary for health, either because science has found a way of manufacturing a cheap substitute (like margarine for butter)

which does not naturally contain vitamins, or because the method of manufacture (like some kinds of canning) or the method of transport (like some kinds of refrigeration) destroys the vitamins originally present. Also it is often difficult to get enough sunlight, fresh air, and exercise in a big city.

Largely as a result of these facts, the people of industrial nations are very far from healthy. For instance, in our own country, nearly three-quarters of the children have decayed teeth, and nearly a quarter have something the matter with their ears. Certainly more than half (probably a good deal more) are considerably less tall and heavy and strong than they might be. Certainly more than half of the whole population, grown-ups as well as children, are much more susceptible to diseases of many kinds than they would be if they ate the right kind of food and lived in healthy surroundings.

So science, as the result of its past advances, has new demands made upon it in the present. It must, for instance, find out how to develop smokeless fuel from coal, how to preserve the vitamins in canned and refrigerated food, how to put vitamins into foods which lack them, and so on. Already a great advance has been made with both these problems. The best modern methods of canning and refrigerating foods leave their vitamins as well as their taste almost unaltered. We can now burn coal at central generating stations to produce electricity, or treat it to produce gas and coke and tar, or treat it in other ways to produce motor spirit and smokeless household fuel. It remains to make the results of these methods cheap enough for everybody to enjoy, and also to persuade people to abandon their old habits.

Similarly in past centuries, the crowding together of

people into big cities with no proper sanitary arrangements made it possible for certain infectious diseases to spread much faster than with a scattered population, and the result was that from time to time terrible plagues and pestilences broke out. One of the last in England was the Great Plague of London in 1665, when 70,000 people died. Since that time, better sanitation and stricter precautions against infection, framed on the basis of scientific knowledge, have prevented the recurrence of such plagues in the cities of civilised countries.

The Main Steps in the History of Science

When we look back at the history of science, we can distinguish a few main stages, each of which has a very distinct character of its own. First there is the stage of antiquity. During most of this long period, from the dawn of history to the fall of the Roman Empire, science was not an organised system of ideas, but grew rather haphazard out of men's practical needs. We have explained how geometry arose out of land-measuring, and astronomy out of the need for a calendar. In the same way scientific geography later grew upon the foundation of travel and commerce. In classical Greece there was also a great outburst of scientific speculation about nature and its elements, but for the most part it remained mere speculation, with little or no contact with practical life. In the Greek city of Alexandria, towards the end of the period, there was some attempt at making science more practical, and also at arriving at some general system of scientific ideas, but the civilisation of the ancient world began to collapse before this movement could bear much fruit. In the most general way, we can say that ancient science was rather unorganised, and that speculation and

theorising on the one hand and practical applications and technical skill on the other were kept much too separate.

Next came a long period of about a thousand years—the period of the Dark and Middle Ages—in which there was very little of the scientific spirit in Europe. What advances there were, were made mainly by the Arabs; but, apart from mathematics and some practical chemistry and medicine, there was little progress. This long unscientific period shows us that there is no necessity for science to progress. The scientific spirit can be checked or discouraged by the general ideas of the time, and if this happens, naturally science and its applications will not advance.

Then comes the period from the sixteenth to the late nineteenth centuries, marked by the birth of modern science and its growth into an organised system of ideas. Modern science differed from ancient science in several ways. In the first place, it rejected the idea of arguing from general principles, which we have seen was prevalent both in antiquity and in the Middle Ages, and laid down that the only scientific method was to let theories grow out of facts, and then test their correctness by means of experiment. As a result of this, the connection between theory and practice was much closer than in antiquity, and scientific knowledge speedily found useful application. We need only think of navigation being made safer and more accurate by Newton's work, of the practice of medicine and surgery being completely changed as a result of Pasteur's discoveries, of the growth of the electric power industry out of the pure researches of Faraday.

A further very important difference was the increasing stress laid on quantitative thinking and quantitative methods—in which we not only try to get a general answer, but one which will fit accurately. Modern science is

always asking "How much?" For instance, it used to be supposed that the atmosphere, apart from water vapour and carbon dioxide, was all made up of the two gases oxygen and nitrogen. However, when very accurate quantitative methods were used, a small residue was left, and this residue was found to consist of a number of new elements, some of which, like neon, are now of great practical use. Still earlier, it was the quantitative work of men like Lavoisier, weighing all the substances that went into and came out of chemical reactions, which led to the proof of the existence of atoms, and of the indestructibility of matter.

Sometimes thinking quantitatively will suggest how a problem should be solved. When Harvey calculated just how much blood the heart would pump in an hour, he at once saw that the old idea of an ebb and flow of blood in the veins and arteries would not work, and this was one of his reasons for searching for a circulation of the blood. Instead of looking to qualities and general principles, modern science came to find that accurate measurement and quantitative thinking was the best scientific method.

Yet another difference was that men of science soon began to make a practice of publishing their work in special scientific journals, and of publishing not only their conclusions but also all the facts and experiments from which they drew their conclusions. This enabled other scientists to check the facts, and, if they wanted to, to repeat the work and see if perhaps a mistake had been made. In both these ways, an advance was made over the methods of ancient science.

As time went on it became clear that the various branches of scientific knowledge, however different they might seem at the outset, were all connected. By the second half of the nineteenth century it was realised

that all matter, whether it were in a star or a stone or a human body, was made of the same elements, and all kinds of activity, whether in a volcano, a dynamo, the heat of the sun, or the movements of a man, were different manifestations of one and the same store of energy. This meant that the different branches of science not merely had a method in common, but had become a single organised body of knowledge.

During this period, practical applications had generally followed rather haphazard from the discoveries of pure science. The next period, in which we are now living, is one in which science, as well as being pursued for its own sake, is deliberately set to find answers to practical questions. For instance, big chemical works to-day are not content to wait until some scientist working in the chemistry laboratory of a university happens to make a discovery which may be useful to them in their practice; they have laboratories of their own, in which the scientific problems arising out of their practical needs are thoroughly studied. Similarly, when it became clear that the problem of the best way of refrigerating food was of great practical importance, the Government founded a big research laboratory at Cambridge to study the question in the broadest possible way.

Practical men have now realised that in the long run the best method of getting an answer to a practical problem is to investigate it scientifically, even if at times this means that the scientists are studying things that seem very remote from practical application. As a consequence of this, the present period is a period of scientific research institutes. Some of them are in the works of private firms, others are supported jointly by many firms in one industry, others by the Government. Such research institutes exist to study

chemistry, electricity, agriculture, aviation, coal-mining, fisheries, building problems, wool and cotton, refrigeration, steel, medicine, and many other subjects.

This does not mean that pure science for its own sake has been neglected. On the contrary, it has been realised that most of the really important new advances, both in scientific knowledge and in practical applications, arise in laboratories of pure science, and in most countries these are being partly supported by Governments. So we may say that we are now living at the opening of a new period, in which science, after becoming organised as a body of knowledge, is being deliberately organised to satisfy practical needs.

The Succession of Subjects Studied by Science

Finally, we see that during the history of science there is a more or less regular succession of the subjects to be studied scientifically. Geometry and astronomy were among the earliest subjects, soon to be followed by geography and natural history. Some attempt was early made at a scientific study of physics, chemistry and medicine, but these were too complicated for ancient science to make much real advance.

On the rebirth of science after the Renaissance, the same sort of thing was seen. It was in astronomy and mechanics that the first great advances were made, and, on the biological side, in the descriptive science of anatomy. The discovery of the circulation of the blood was largely a conclusion drawn from the facts of anatomy.

Then, in the eighteenth century, there came a great advance in fundamental physics and chemistry, and, on the side of the descriptive sciences, in natural history and classification, and a little later in geology.

In the nineteenth century, much attention was paid to electricity and to organic chemistry, until by the last quarter of the century physics and chemistry had become a single organised body of rapidly advancing knowledge, with which astronomy soon became linked. It was not until the nineteenth century that either physiology or general biology could be scientifically attacked with much hope of success, but during this century enormous strides were made in both these sciences. Anthropology, or the scientific study of man, was not properly begun until the middle of the century, and it was not until still later that either psychology, the scientific study of the human mind, or sociology, the scientific study of human society, was seriously pursued.

As is only natural, it was in the simpler subjects that great scientific advances were first made; the more complicated ones had to wait until later. But besides this, there is another reason why the scientific study of some subjects lagged behind that of others, and that is the amount of prejudice to be overcome. This is especially seen in the sciences concerning man. The prejudice against cutting up dead bodies hindered the advance of anatomy and medicine. The prejudice against admitting that man was not specially designed as Lord of Creation stood in the way of Darwin's theory of evolution being accepted, and especially of its being applied to the origin of man. The natural prejudice we almost all of us have about our reasonableness and our high ideals are to-day standing in the way of advance in psychology, just as political prejudices are hindering scientific sociology.

However, the history of science shows us that in the long run prejudices can be surmounted, and that the practical needs of the situation slowly but surely lead to their

being first scientifically studied and then brought under control by applying the scientific knowledge gained.

At the moment, the most urgent needs of our situation concern social affairs and social systems. While we have found out a great deal about harnessing the forces of lifeless nature, and also can control animals and plants (such as disease germs, insect pests, crop plants and domestic animals) quite reasonably well, various social processes are giving the world a great deal of serious trouble.

For instance, something is wrong when factories have to slow down production and yet there are millions of unemployed; and when good wheat land is not cultivated, or good coffee is burnt instead of being sold, or good fish thrown back into the sea, and yet there are millions of people not getting enough food. Something is wrong when terrible wars are still possible, or when people, as in some countries, are not allowed to say what they really think, or to know what is really going on.

We have to make up our minds to find out why such things happen and what are the scientific reasons for them, and then to use our knowledge to control social affairs more efficiently.

But to make any big change in social affairs will not be possible unless the right sort of ideas are widespread in the population. People must be prepared for change: they must be willing to think about social affairs in a scientific way, without violent feelings and prejudices, so that they can decide impartially what sort of change would be bad and what would be good. They must learn that science is not merely something which deals with physics or chemistry or with the way plants and animals live: science can also deal with human life, and the scientific spirit is just as important in human affairs as in the laboratory or the workshop.

Change is always happening. The earth was once too hot for liquid water to exist upon it: gradually it changed so that oceans formed and then life could appear. All life at first consisted of very simple tiny creatures: gradually it too changed, and bigger and more wonderful kinds of animals and plants came to exist, until at last one kind of animal slowly changed into man.

Human ways of life have steadily changed. Before about ten thousand years ago, man lived entirely by hunting. A settled civilised life only began when agriculture was discovered. From that time to this, civilisation has always been changing. Ancient Egypt—Greece—the Roman Empire—the Dark Ages and the Middle Ages—the Renaissance—the age of modern science and of modern nations—one has succeeded the other, and history has never stood still. Even if we try to do nothing, we cannot prevent change. During the last few years change has been even more rapid than usual. The Great War, the Peace Treaties, the rise of wireless and flying, the revolutions in Russia and Germany, the world crisis with all its unemployment and unhappiness and the new ideas it is putting into people's minds—all these have been changing the world under our eyes.

In the past, people have usually been unconscious of social changes until they have happened. Now many people are realising that changes are happening. The next step is to study economic and social change and find out how to control it deliberately instead of letting it control our life by just happening. And for that, science is needed. Without science and the scientific spirit, we shall just drift along; with their aid, man may be able to learn how to control his own destiny.

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